CETACEAN DISTRIBUTION IN ECUADOR: SPATIAL AND TEMPORAL RELATIONSHIPS BETWEEN OCEAN FRONTS AND THE APEX PREDATOR POPULATION

A Dissertation

by

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ABSTRACT

Five line transect surveys for marine mammals were conducted offshore of mainland Ecuador and the Galápagos Islands between 2008-2011. These data were used in conjunction with MODIS (Moderate Resolution Imaging Spectroradiometer) observations of ocean color and sea surface temperature (SST) to assess spatial and temporal relationships between surface oceanographic features and cetacean distribution within the Eastern Equatorial Pacific (EEP). Results from this study indicated that oceanographic processes affected cetacean distribution on inter-annual, seasonal, and weekly to monthly time scales. The spatial scales on which these processes affect cetacean distribution are small, the smallest associations being found at 4 km^2 bin sizes, as well as 9 km^2 and 36 km^2 bin sizes. By utilizing ocean color and SST data from the MODIS instrument and analyzing variability of these parameters in addition to average concentration, cetacean distribution within the region was related to the locations of frontal boundaries. Cetaceans were grouped into two categories based on the trophic level and relative depths at which they forage. Cetaceans feeding nearer the ocean surface and lower on the trophic scale were generally found in cooler waters of higher average chlorophyll concentration and elevated variability. Those cetaceans feeding higher on the trophic scale and lower in the water column (mesopelagic and bathypelagic depths) were sighted within relatively warmer waters of reduced temperature variability near areas of high chlorophyll variability (though less variable and lower in average

chlorophyll than surface feeding cetaceans), with little spatial and temporal lag between peak surface chlorophyll concentration and cetacean presence.

The EEP is a biologically productive region with many competing economic and environmental interests. Ecuador is home to one of the largest artisenal fishing fleets in South America, and entanglement of various cetacean species has been a known issue for several decades (Félix and Haase, 2006; Castro and Rosero, 2010). Seismic exploration, shipping, and tourism are also found on the busy waterways surrounding both mainland Ecuador and the archipelago. The results of this study provide additional insight into the mesoscale processes affecting the distribution and habitat use of cetaceans within the EEP and South American waters and to support ongoing ecosystem management efforts.

DEDICATION

For my grandmother, Lucille Kenney Johnson, and my family.

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"The fish are in the sea with the wales. There are blue ones red ones big ones little ones funny ones stupit ones. Some fish even eat other fish and the other fish get eaten. Wales are bigger then most fish. Some fish are around structure and others are in the open sea." – Captain Mike

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CHAPTER I

INTRODUCTION: MARINE MAMMAL SURVEYS IN THE EASTERN EQUATORIAL PACIFIC

The country of Ecuador straddles the equator along the western face of the South American continent. Its seas extend away from the continent to encompass the Galápagos Archipelago. Oceanographically, geologically, and culturally this part of the world is a truly unique place. As part of an educational and scientific agreement between Texas A&M University (TAMU) and the Oceanographic Institute of the Ecuadorian Navy (INOCAR), ship space was made available to TAMU students aboard the *B/I Orion* during INOCAR's semi-annual oceanographic research cruises in the Eastern Equatorial Pacific (EEP).

In 2008, TAMU began surveys for marine mammals aboard the Navy research vessel *(Buque de Investigación) B/I Orion*. These marine mammal surveys continued for five consecutive cruises over four years. Four surveys were conducted during the rainy season of September/October and one survey was carried out during the dry season in April. Observations were made by myself, researchers from the NOAA Southeast Fisheries Science Center (SEFSC), graduate students from TAMU, students from the University of San Francisco, Quito (USFQ), and by volunteers from the Ecuadorian Foundation for Marine Mammals (FEMM). While the ship was underway and weather

conditions permitted, observers kept watch during daylight hours from the flying bridge. Students, scientists, and volunteers aboard the ship supported several different projects and came from all over the North and South American continents.

Since the *Orion* was primarily tasked with a hydrographic survey following pre-determined East-West transit lines and North-South transect lines along which the ship stopped to make regular sampling stations, we could not close on sighted groups of animals. Using just 7x50 mm binoculars and a 400 mm camera lens to make observations, groups of cetaceans were identified to the lowest taxonomic level possible. Many groups were identified to genus or listed as un-identified in order to preserve the best accuracy of our records. Observers noted environmental conditions and survey effort so as to compile a record of cetacean absence in addition to cetacean presence. From these records, an abundance estimate was made for the entire cetacean population within the EEP and compared with those estimates made by NOAA's Southwest Fisheries Science Center for the entire Eastern Tropical Pacific.

Satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were collected for the area covered by each survey and for the study area as a whole during the time periods covered by each survey. Ocean color serves as a useful proxy for both biological and physical oceanographic processes and can help us understand why large apex predators such as dolphins and whales are present in any particular area at a particular time. Spatial and temporal lags between surface chlorophyll and cetacean

presence/absence were evaluated as well as monthly composited sea surface temperature. Finally, areas of high variability in surface chlorophyll were assessed in relation to their distance from cetacean presence and absence.

Overall, cetaceans were found throughout the study area, in both oceanic and coastal waters. Cetaceans varied in their spatial and temporal lags to surface chlorophyll, but generally demonstrated strong relationships with areas of high variability in surface chlorophyll and so were present relatively near areas identified as ocean color fronts.

INOCAR plans continue its oceanographic surveys into the future, and hopefully, the marine mammal surveys will continue as well. Time-series observations of marine mammals aboard the *Orion* will augment conservation and ecosystem-based management of marine mammals within South American waters and promote future educational and research opportunities in the field of marine mammal science.

CHAPTER II

CETACEAN ABUNDANCE IN ECUADOR: ESTIMATES FROM TWO DIFFERENT LINE TRANSECT SURVEY PROGRAMS, 1999-2011

Summary

Cetacean abundance was estimated for waters westward from mainland Ecuador and the Galápagos Islands using data collected from five oceanographic surveys aboard the Ecuador Navy ship *B/I Orion* and three surveys carried out aboard U.S. vessels as part of NOAA's *Stenella* Abundance Research (STAR) program. The survey area for this study extended from the South American coast at 1.5°N to 3.5°S westward to 95°W and encompassed 895,480 km^2 of the Eastern Equatorial Pacific (EEP). This region is just a fraction, 4%, of the larger Eastern Tropical Pacific (ETP), one of the most productive ecosystems in the world. To estimate cetacean abundance for a relatively small area, sightings were drawn from multiple years and two different line-transect survey programs. Using distance-sampling techniques, a total cetacean abundance of 282,253 individuals (CV=15.4%) was predicted to reside within the study area. Common dolphin (*Delphinus delphis*) abundance was estimated at 133,021 individuals or 44.3% (CV = 20.7%) of total abundance and striped dolphins (*Stenella coeruleoalba*) at 38,271 individuals (CV = 17.5%) or 12.5% of total abundance.

Introduction

Marine mammal and human interaction within the Eastern Equatorial Pacific (EEP) began in the 18th and 19th centuries with the advent of the region's whaling industry (Townsend, 1935). Whaling expeditions continued through the early 20th century, but scientific observation of cetaceans did not begin until the 1950s and 1960s (Clarke, 1962; Loesh, 1966). In the 1980s Hal Whitehead's research group from Dalhousie University began studying the sperm whale (*Physeter macrocephalus*) population around the Galápagos Islands and off the Ecuadorian mainland coast (Whitehead and Waters, 1992; Dufault and Whitehead, 1993; Smith and Whitehead, 2000). From 1988-1989, the research vessel *Siben* made surveys primarily for sperm whales around the Galápagos Islands (Lyrholm, 1992) and then in 1993-1994 and 2000, the *R/V Odyssey* conducted multiple marine mammal surveys near the Galapágos Islands (Palacios, 1993; Palacios, 1999). Between the end of the 1980s and the present, NOAA Southwest Fisheries Science Center has conducted surveys throughout the Eastern Tropical Pacific (ETP) to assess the effects of the yellowfin tuna (*Thunnus albacares*) purse seine fishery on dolphin populations (e.g., Au and Perryman, 1985; Fiedler and Reilly, 1994; Jackson et al., 2004). Detailed study of the migratory humpback whale population along Ecuador's mainland coast is still underway (Félix and Haase, 2001), providing valuable behavioral and abundance data for management and conservation efforts. Marine mammal surveys conducted aboard the B/I *Orion* of the Oceanographic Institute of the Ecuadorian Navy (INOCAR) that occurred in August 2000 and September 2001 identified seven species of cetaceans within Ecuadorian oceanic waters.

Common dolphins (*Delphinus delphis*) and short-finned pilot whales (*Globicephala macrohynchus)* were identified as the most abundant species and the absence of sperm whales was noted as the most significant departure from previous mammal surveys.

For the abundance analyses in this paper, data collected during the months of September through November were combined from five transect surveys, 2008-2011, aboard the *B/I Orion,* reported data from a 2001 survey aboard the *Orion*, and reported data from of three surveys made as part of NOAA's STAR (*Stenella* Abundance Research) surveys (Kinzy et. al, 2001; Jackson et al., 2004) were utilized. These data provide information on groups of cetaceans sighted in the oceanic waters extending from the coast of Ecuador, through the Galápagos National Wildlife Refuge, and west to 95°W longitude (Table 1, Appendix A). By using multiple years of surveys that span more than a decade, inter-annual variation is not measured, rather the abundance of a smaller subsetted region of the larger ETP, the EEP, was assessed. There were too few sightings each year to assess inter-annual variability in cetacean abundance. Instead, the goal was to improve precision of the cetacean abundance estimates within the EEP by using multiple years and platforms of survey effort. Models of the sighting probability aboard the *Orion* are based on the sightings from 2008 and 2011.

Methods

Field Surveys

The *B/I Orion* is a 70 m oceanographic vessel and maintains average cruising speeds of 7-10 knots, which constituted the survey speed. During 2001-2011 cruise the *Orion* followed pre-determined North-South tracklines and East-West transit lines and made regular oceanographic measurements at CTD (Conductivity Temperature Depth) stations. The visual surveys were conducted from the flying bridge, 9.8 m above the waterline, during all daylight hours (approximately 0600-1830 hrs). Effort was suspended when the ship stopped for CTD stations, thirty minute meal times, and times when weather conditions did not permit a clear view of the transect (heavy rain and Beaufort sea states >5).

While observers were actively searching for mammals, "on effort mode," 2-4 observers used Bushnell 7x50 binoculars to scan from the ship out to the horizon. A starboard observer scanned 90º right of the bow to 0º directly in front of the bow and a port side observer was responsible for 90º left of the bow through 0º in front of the bow. One observer was responsible for keeping notes on survey effort, environmental conditions and sightings. Sightings were only recorded while the ship was underway, under conditions of good visibility and full sunlight and with Beaufort states not > 5.

In September 2008, cruise track and sighting locations were taken from the ship's GPS and log. During the 2009, 2010, and 2011 cruises, the cruise track and sighting locations

were recorded using a handheld Garmin GPS connected to an IBM laptop. During the 2008 and 2011 cruises, observers used the reticles and compass built into the binoculars to determine distance from the ship to initial cetacean group sighting.

Observers confirmed species only when the cetacean group came close enough to the ship that observers could clearly see the animals or photograph the animals using a Canon EOS Digital Rebel XS 10.1 megapixel camera and 300-400 mm lenses. Field observation during the 2008-2011 surveys followed, as closely as possible, the line-transect methods described in Mullin and Fulling (2004). Field methods employed during the 2001 *Orion* cruise and NOAA SWFSC STAR cruises were similar and are described in Clarke et al. (2001) and Gerrodette et al. (2008). Figure 1 displays survey effort for all eight cruises (Please, see Appendix A for all figures and tables listed in this chapter).

Surveys aboard the *Orion* and those carried as part of NOAA's STAR program differed for several reasons. First, the STAR cruises are dedicated marine mammal surveys where the ships are diverted from the trackline to approach and identify groups of animals. *Orion* surveys were conducted in passing mode and continued with the line transects and did not approach sighted groups of cetaceans. STAR cruises also utilize a large number of trained observers that rotate watches on regular intervals. These observers utilize 25x150 mm "Big Eye" binoculars that results in larger number of sightings and a much larger half strip width than the smaller 7x50 mm binoculars used

by observers on the *Orion*. The *Orion* cruises are also used as training cruises for graduate students new to marine mammal observing. Typically, two trained observers worked with student observers and rotate as needed. As in other surveys conducted on ships of opportunity such as those described in Williams et al. (2006) and Palacios et al. (2009), observers aboard the *Orion* followed as close as possible line transect methods for estimating cetacean abundance.

Analytical Methods

The methods used for this analysis were meant to provide the most comprehensive estimate of cetacean abundance possible within Ecuadorian waters. Data were compiled from eight separate cruises conducted during the September/October rainy season over a twelve year time period. Three of the datasets were obtained from NOAA STAR cruises. The NOAA cruises encompassed the entire Eastern Tropical Pacific, so only those sightings and survey effort that occurred within my study are of 1.5°N and 3.5°S and 79°W and 95°W were included in this analysis. All of the positions were converted to decimal degrees to conform to the records kept aboard the *Orion*. Figure 2 is a histogram of all initial sighting distances from aboard the *Orion*. These sighting distances are used to model a detection function (g(x)) for sightings made aboard the *Orion*. Histograms help reveal potential biases in the sighting data such as heaping, measurement errors, and evasive movement of cetacean groups prior to detection (Buckland et al., 1993).

Methods for calculating cetacean abundance followed those of Buckland et al. (1993) with some modifications, as explained below, made for estimating probability density function at zero perpendicular distance from the trackline in kilometers. In order to use distance-sampling methods, several assumptions must be met during the field sampling process. First, no cetaceans on the trackline that the ship surveys may go undetected. Secondly, no movement by a sighted cetacean should occur before detection by an observer on the ship. Lastly, distances must be measured without error and the sampling size must be of adequate size (Buckland et al., 1993). As in Wade and Gerrodette (1993), sightings were pooled from multiple years to estimate the population for a single area. For data collected aboard the *Orion*, distances between the ship and initial sightings were measured only during the 2008 and 2011 cruises. Radial sighting distances were calculated according to the formula from Lerzack and Hobbes (1998),

$$R = (r + h) * sin(\alpha + \rho * C - \sqrt{(r^2 - [(r + h) * cos(\alpha + \rho * C)^2])}$$

Where ,

R is the radial sighting distance

h is the binocular (eye) height = 0.0112 km (9.8m height of Orion plus ~1.4m for eye height of observer)

r is the radius of earth = 6371 km

$$\alpha = atan(\frac{H}{r})$$

Where H is distance to horizon in km.

$$H = \sqrt{2 * r * h + h^2}$$

rho = reticle reading

C = radians/reticle, pre-calculated by Kinzey and Gerrodette (in review) to be .00487 for 7x binoculars; varies slightly by style which translates into discrepancies of about .03nm

Perpendicular distance was calculated from the radial distance and the bearing between the ship and initial sighting.

$$P = R * sin(\theta)$$

Where:

P is perpendicular distance

θ is horizontal angle between trackline and sighting

Two different models were tested to estimate the detection function *g*(x). A half normal model of form:

$$g(x) = exp(\frac{-(x^2)}{2 * \theta^2})$$

where,

x is the perpendicular distance in kilometers between the trackline and initial sighting

σ is a scale parameter

and a two parameter hazard-rate of form:

$$g(x) = 1 - exp(-(\frac{x}{\theta}) - b)$$

where,

σ is again the scale parameter and b a shape parameter

$$\sigma = (\frac{c}{d-1})^{\frac{1}{d-1}}$$

b = d-1

d is a discrete variable set so that b>= 1

c is set to one since both sides of the transect were observed in this study.

(Buckland et al., 2001)

The two models for the detection function, a hazard-rate model and half-normal model, are plotted in figures 3 and 4 as a comparison against the distribution of initial sighting distances shown in figure 2.

Akaike's Information Criterion was used to select the most appropriate model. AIC values were calculated for each model according to the form presented in Buckland et. al. (2001).

$$AIC = -2 * \log_e(L) + 2 * q$$

Where,

$\log_e(L)$ is the log-likelihood function evaluated at the maximum likelihood estimates of the model parameters

q is the number of parameters in the model.

The differences between each model's AIC and the smallest AIC were computed and

then Akaike weights were found according to the form,

$$w_i = \frac{\exp(-0.5\Delta_i)}{\sum_{j=1}^{6}\exp(-0.5\Delta_j)}$$

Based on the Akaike weights (Table 3), the first half-normal model, the model with the highest relative likelihood, is the most appropriate for this dataset. Truncating observed distances at 3.5 km did not make any difference to model fit and so data were left untruncated. The number of observers and sea state also appeared to have a negligible effect on initial sighting distances (see Appendix for figures 5 and 6).

Since $g(0)$ is assumed to be 1, i.e. all animals directly on the trackline were sighted, the probability density function at zero distance from the trackline, $f(0)$, was estimated from the detection function, $g(x)$.

$$f(0) = \frac{g(0)}{\int g(x)dx} = \frac{1}{g(x)dx} = 1.28$$

Variance of $f(0)$ was calculated as shown in Buckland et al. (2001) by:

$$var(0) = \frac{1}{n * \pi * \sigma^2} = \frac{f(0)^2}{2 * n}$$

Variance of the number of sightings made each year, n, was based on the variation in the number of on-effort group sightings between sampling years/cruises.

$$var(n) = \frac{L_{total} * \sum l_{year}(\frac{n_{year}}{l_{year}} - \frac{n_{total}}{L_{total}})^2}{n_{total} - 1}$$

The *f(*0*)* estimated here was only applied to sightings made from the *Orion*. The different observation platforms and equipment of the *Orion* and NOAA ships produced very different probabilities of detection and sighting functions. This is most likely due to the differences in equipment used, the more powerful binoculars employed by NOAA cruises compared to the 7x50 mm binoculars used aboard the *Orion* permitted a wider half-strip width of trackline and earlier detection of animals on the trackline. NOAA cruises also encompassed the entire ETP, so their detection probability functions are influenced by sightings outside this study area. NOAA published the positions and dates of each sighting, as well as the values of *f*(0) for each species stock (Gerrodette et al. 2008), and these values of *f* (0) were applied to the corresponding cetaceans that were included in this study and sighted from NOAA ships. Where no published *f*(0) value existed for a particular species, an average *f*(0) for all sighted species within the same year was used (The *f*(0) for NOAA sightings are published values calculated for all sightings within NOAA's study area of the ETP). Statistics for *f*(0) are summarized in Table 4 to allow a comparison between species and sighting platforms. Only those reported number of sightings for each taxa/populations and group sizes from within the Ecuador study area were used for statistical analyses.

Abundance (N) was calculated from the probability density function as described in Buckland et al. (2001). The sampling unit for these estimates was the cruise year, not individual track lines. One potential problem with this approach was 'double-counting' groups that either advanced west through the study area were re-counted during the

ship's return to Guayaquil, which would have resulted in a positive bias to the abundance estimate. However, since transects were spaced several degrees apart and groups of the same species rarely observed during both transects and the return transit, observers did not find that they were re-sighting the same groups.

In order to make use of survey effort and sightings from both NOAA and *Orion* cruises, the summed values of [n* $f(0)$*s] for each year were computed separately for NOAA versus *Orion* cruises. These summed estimates were then summed together and multiplied by the area divided by twice the trackline distances [A/2L], for a final abundance estimate.

NOAA surveys:

$$\sum [n*f(0)*s]_{D.delphinis-year}, [n*f(0)*s]_{S.coeruleoalba-year}, [n*f(0)*s]_{GeneralCetacean-year}$$

Orion surveys:

$$\sum [n*f(0)*s]_{GeneralCetacean-year}$$

Combined surveys:

$$NOAAsurveys; Orionsurveys * \frac{A}{2L}$$

Abundance estimates were made for the entire survey area of Ecuadorian waters as well as two subset regions. These subset regions included the offshore area stretching between 82°W to 89°W where water is generally deep and less biologically productive as well as those waters adjacent to the Galapagos National Reserve (GNR), using an area extending from 88.9°W to 92.5°W and 1.0°N to 1.5°S. Variance of the abundance

estimate N was calculated by bootstrap with 400 bootstrap samples according to the methods in Buckland et al., 2001. A bootstrap sample was constructed by sampling survey effort from each cruise with replacement.

In addition to the general cetacean abundance estimates made using a combined pool of NOAA and *Orion* based sightings, an estimate of general cetacean abundance using only data from NOAA cruises and an estimate made by using only data from the *Orion* cruises were made for comparison. Abundance estimates for common dolphins (*Delphinus delphis*) and striped dolphins (*Stenella coeruleoalba*) using the combined data and the NOAA data were also calculated for Ecuadorian waters. These were the only two species for which there were sufficient sightings to make species-specific abundance estimates.

Survey area was calculated using ArcGIS 9.2 software to create a shapefile and calculate overall survey area as well as the offshore area between the Galápagos and coastal Ecuador. Survey effort reported in the NOAA technical memoranda (Kinzy et al., 1999; Kinzy et al., 2000; Clarke et al., 2001 and Jackson et al., 2006) were used with the measured effort of the other four surveys aboard the *Orion*. All areas and distances were converted to square kilometers or kilometers, respectively.

Results and Discussion

Using these modified distance sampling methods and the entire dataset of pooled NOAA and *Orion* based sightings, a cetacean abundance of 282,253 (CV = 15.4%) is found to reside within waters between the Ecuadorian coast and 95°W. A total of 11,108 km of survey effort from 5 different years of survey aboard the *Orion* and 3,125 km of effort reported from 3 separate years of NOAA STAR cruises provided data on 321 cetacean sightings (131 sightings from NOAA ships and 190 sightings from the *Orion*). Incorporating data from two different survey programs across multiple years increased the amount of study area that was surveyed and the number of cetacean groups sighted, which increased the precision of cetacean abundance for this local region of the EEP. Population estimates for the study area and sub-regions, offshore waters and waters of the Galápagos National Reserve, are summarized in Table 5.

Using only the sightings and effort data from NOAA cruises produced an estimated regional abundance of 387,290 (CV =17.3%) cetaceans. Conversely, when cetacean abundance was calculated using only data from the *Orion* cruises, the estimate was reduced by about a third to just 252,706 (CV=29.3%) animals. While these estimates are not statistically different, the discrepancy is largely explained by two factors. First, the difference in the areas of survey effort: NOAA survey time was more heavily weighted toward the mainland coast and Galápagos Islands, while over half of the survey time aboard the *Orion* was spent in deep, offshore waters. In these deeper waters of the EEP, known, preferred habitat of the species observed in this study was more ephemeral and

spread out than in nearshore waters (Davis et. al., 1998). Using data both from the *Orion* and incorporating data from NOAA cruises into an offshore cetacean abundance estimate produces an estimate of 282,253 cetaceans (CV = 15.4%). This estimate translates to a density of 320 animals per 1000 km^2. The density of cetaceans within waters adjacent to the Galápagos National Reserve was almost double the offshore density at 448 animals per 1000 km^2. The density of cetaceans within offshore waters was 242 animals per 1000 km^2.

Second, observers aboard NOAA cruises sighted much larger groups of dolphins than observers aboard the *Orion*. The mean cetacean group size for NOAA sightings used in this analysis was 68.7 (CV=14.3%) whereas the mean group size sighted aboard *Orion* cruises was 15.5 (CV=12.5%). This disparity between group sizes is most likely due to observer biases, since *Orion* cruises do not approach cetacean groups and use only 7x50 mm binoculars.

Table 6 summarizes population estimates from the NOAA and *Orion* ships for comparison of population estimates between platforms. The disparity between estimates from NOAA and the *Orion* highlights important features of both the cetacean distribution within Ecuadorian waters and potential problems from mixing data between different line transect programs. Barlow et al. (2001) found that while many factors may influence $g(0)$ and thereby the abundance estimates made from line transect data (accuracy of sighting measurements, sea state, etc.), neither the platform, i.e., ship, nor

the year generally make a significant difference when estimating $g(0)$. However, this assumption only held true when survey methods and equipment were similar between observing platforms. Since the *Orion* was a platform of opportunity, deviations from protocol used aboard the NOAA ships was sometimes necessary.

A major assumption of distance sampling methods used aboard ships at sea is that all objects along the trackline are counted. This is the most likely violation of theory from *Orion* surveys. Ship avoidance by many species likely negatively biases the dataset, particularly when estimating taxa specific cetacean abundances. Over a third of the sightings collected from the *Orion* could not be identified beyond the family taxonomic level. Observers noted during many of their sightings that groups either actively avoided the ship, or at best, did not approach the ship. This is a known behavior of many cetacean species within the ETP, particularly those historically targeted by the purse-seine fishery industry. Typically skittish animals may dive or divert course before the vessel is close enough for observers to sight them (Palker and Hammond, 2001; Barlow et al. 2001; Scott and Chivers, 2009). Overall, species diversity at the genus level was about the same between sightings aboard the *Orion* and NOAA cruises, though sightings of species that might avoid ships in the ETP (beaked whales, *Kogia spp.,* and spotted dolphins) were fewer from the *Orion* than NOAA cruises and generally not identified to as low of a taxonomic level. The use of "big eye" binoculars utilized aboard NOAA ships minimizes the chances that skittish or deep-diving animals react to the presence of the ship before they are sighted. This advantage is evidenced by the larger effective half

strip width of NOAA cruises over *Orion* cruises. The average effective half-strip width for NOAA cruises used in this analysis was 2.99 km. The effective half–strip width aboard the *Orion* was just 0.78 km. The larger half-strip width of NOAA surveys also explains the higher sighting rate than that of the *Orion* surveys.

Since there was not a sufficient number of sightings of each species during individual *Orion* cruises, we could not calculate species specific probability density functions ($f(0)$). NOAA cruises, using the entire ETP, calculated species specific $f(0)$ for ten species each year, including common and striped dolphins. These two species were frequently identified during *Orion* cruises and we used their corresponding NOAA $f(0)$ in conjunction with the *Orion* cetacean $f(0)$ to improve abundance estimates of these two populations within Ecuadorian waters. The $f(0)$ calculated for all cetacean sightings from the *Orion* was applied to sightings of striped and common dolphins sighted from the *Orion* and the species specific $f(0)$ for each year of the NOAA cruises was applied to the species' sightings from the NOAA cruises. These values were then combined in the same manner as was previously done for total cetacean abundance. However, using $f(0)$ calculated from data obtained from the entire ETP will slightly influence the abundance estimates with data from outside the study area.

When using only the pooled NOAA data, short-beaked common dolphins were more abundant than striped dolphins. The 95% confidence interval ranged from 118,420 to 391,263 animals for the short-beaked common dolphin and 38,967 to 95,257 for striped

dolphins. Common dolphin groups were sighted about every 334 km and striped dolphins every 442 km. Figures 7 and 8 are the locations of all sighted common and striped dolphins from both NOAA and *Orion* cruises and depict the general distribution of these two most frequently sighted species.

This result suggests that common and striped dolphin abundance within Ecuadorian waters may be slightly lower than that of the overall ETP. The ETP area surveyed by NOAA comprises 21,353,000 km^2. The area in the study area between Ecuador mainland and 95°W, excluding the landmass of the Galápagos Islands, is about 4% of the ETP survey area, just 895,480 km^2. Taking the mean estimated abundance for short-beaked common dolphins and striped dolphins in 1999, 2000, and 2003 gives estimates of 2,570,100 animals and 1,231,684 animals, respectively for the entire ETP (Gerrodette et al., 2008). If we were to assume the two dolphin species were equally distributed throughout the ETP, then 4% of those mean population estimates are 102,804 common dolphins and 49,267 striped dolphins, respectively. From our pooled NOAA distance sampling abundance estimates, the common dolphin population appears under-represented with respect to the rest of the ETP, while striped dolphin population is within an expected range.

Dolphin stocks within the ETP are not, however, evenly distributed geographically. Perrin (1975) and the NOAA STAR reports (Gerrodette et al, 2008) found similar distributions for the EEP to those found in this study. The pantropical spotted dolphin

(*Stenella attenuata*) and the spinner dolphin (*Stenella longirostris,* another stenellid species heavily impacted by the purse-seine fishery and of special interest to the NOAA STAR program), were each so rarely identified within Ecuadorian waters that no abundance estimate could be made for them. There are several potential reasons for this under-representation of spinner and spotted dolphins including ship avoidance and lack of preferred habitat. Au and Perryman (1985) speculated that the reduced sighting number of fish/bird assemblages below 4°N indicated a geographical shift in the preferred prey species of epipelagic, apex predators. Spotted and spinner dolphins are more commonly associated with areas of deep thermoclines (>70 m) (Reilly, 1990), north and south of the equator along the warmer Peru Current and near the Costa Rica dome (Au and Perryman, 1985; Reilly, 1990; Balance et al., 2006). The lack of spinner and spotted dolphin sightings within this study area, therefore, was not unexpected given the last several decades of information, although Perrin (1975) did suggest that the preferred range of the whitebelly spinner stock should extend through the EEP.

Common dolphins, along with pilot whales, bottlenose dolphins, Risso's dolphins, and Bryde's whales, conversely, tend to prefer upwelling-modified waters such as those found within this study's survey area, at least on the scales used in previous studies. On relatively broad scales, common dolphins tend to occupy the coldest, most saline waters of the ETP: areas east and west of the Galapagos where they appear with striped dolphins (Au and Perryman 1985, Wade and Gerrodette 1993, Reilly *et al.* 2002, Ballance *et al.* 2006). For these reasons, the apparent under-representation of common

dolphins within our study area is a striking result. In future surveys, great attention to group size under-estimation and responsive movement away from the ship needs to be carefully evaluated, as these two factors could result in a negative bias to the abundance estimate. If common dolphins are truly under-represented within Ecuadorian-adjacent waters, potential anthropogenic causes need to considered and managed.

Species composition and density varied between the study area of the EEP and the wider ETP, density also varied between the EEP and other regions. The sighting rate for cetaceans in the oceanic Gulf of Mexico was about half of the overall sighting rate in the EEP (one cetacean for every 45.2 km as compared to every 23.8 km) (Mullin and Fulling, 2004). By contrast, the population of striped dolphins in the western Mediterranean Sea is estimated to be 117,880 (CI 68,379-214,800), almost 3 times as many individuals as this study region. However, as is the case with the EEP, common dolphins appear to be newly under-represented, for reasons not entirely explained (Di Sciara et al., 1993). Given the relative distributions of cetaceans around the world, the EEP then is still an important region of habitat for cetaceans.

Conclusions

Ecuador lies at the edge of powerful South American upwelling that is driven by a confluence of the Peru Current (Humboldt Current) and the Equatorial Undercurrent. A unique combination of seasonal, inter-annual and inter-decadal oceanographic variability as well as bathymetric features create productive habitat for marine mammals within the

oceanic waters off Ecuador's coasts. The Exclusive Economic Zone (EEZ) of Ecuador encompasses the majority of these waters, although, a small strip of international water splits mainland Ecuador from the Galápagos Islands. For all of these reasons, strict monitoring and law enforcement, particularly in terms of protecting endangered and threatened species, can be difficult. By supporting the collection and analysis of baseline information on cetacean populations within the country, this study will aid future management and research efforts. Human activities in this region still have a powerful impact on cetacean populations. Mangel et al. (2009) found that despite protective legislation in Peru, small cetacean bycatch was still high within the artisinal drift gillnet and longline industries. Additionally, humpback whales have also been associated with the bycatch within the Ecuadorian fisheries (Alava et al. 2005; Félix et al. 2006). Since bycatch is often seasonally affected, baseline population and distribution data can be invaluable for the purposes of sound management policies. It was the early studies conducted by NOAA utilizing fishery observer data that provided scientific evidence that the fishing industry was taking a significant toll on the *Stenella* dolphin populations (Au and Perryman, 1985; Fiedler and Reilly, 1994; Jackson et al., 2004). Without those baseline studies, it would be much tougher today to argue for important conservation measures that promote safer human-cetacean interactions.

Study design will play an important role in the effectiveness of future management protocols. The results of this study do not account for the seasonal fluctuations in cetacean population resulting from the humpback whale migration (Scheidat et al. 2000;

Félix and Haase, 2005; Félix et al., 2006) or the nearshore bottlenose dolphin population along mainland Ecuador (Félix, 1997). These populations are especially sensitive to coastal fisheries, recreational and industrial activities (Van Waerebeek, 1997).

The offshore cetacean population also likely fluctuates seasonally, although there is not sufficient data from the dry season (March-May) to estimate a population for this time of the year. The results from one survey conducted aboard the *B/I Orion* in April 2009 suggest that there is a strong seasonal component to the cetacean distribution. The sighting rate was almost double that of the cruises conducted aboard the *Orion* during September-October (1 cetacean per 37.6 km compared to about 1 cetacean per 60 km). Only the 2011 cruise had a sighting rate comparable to that of the April 2009 cruise.

While the study area of the GNR was only a quarter of the area for middle, offshore waters, the cetacean population was three quarters the size of the middle, offshore population (77,703 animals within offshore waters compared to 53,739 animals for the GNR). Cetacean density within the GNR was twice as high as the offshore density. This leaves the other half of the population residing within mainland coastal waters or offshore waters north, south and west of the archipelago. It will be important for future surveys to delegate adequate survey effort to all three habitat types, particularly accounting for the low density and potential seasonality of the offshore population.

The information gathered in this analysis highlights the importance for continued marine mammal surveys within Ecuadorian waters in a repeatable manner, useable for population studies. Future surveys should be designed to provide coverage through at least three different sub-habitats, near the Galápagos Islands, across deep oceanic water and near the mainland coast. In order to assess seasonal variability in the distribution of cetacean populations, more surveys need to be conducted not just during the region's rainy season (September-November), as those used in this analysis, but during the region's dry season (February-April) as well.

CHAPTER III

OCEAN SURFACE COLOR AND TEMPERATURE OF THE MARINE MAMMAL HABITAT

Summary

Marine mammal sightings from five line-transect surveys conducted offshore of Ecuador and the Galápagos Islands between 2008-2011 were used in conjunction with MODIS (Moderate Resolution Imaging Spectroradiometer) observations of ocean color and sea surface temperature (SST) to assess spatial and temporal relationships between surface oceanographic features and marine mammal distribution. Surveys were conducted aboard the *B/I Orion*, the research vessel for the Oceanographic Institute of the Ecuadorian Navy (INOCAR). Ocean color and SST data were collected from NASA's ocean color browser. The level 2 MODIS imagery was batch processed at 4 km^2, 9 km^2, and 36 km^2 spatial bins and 4 day temporal composites to assess discrete time lags between high chlorophyll a surface values in conjunction with monthly mean SST and the presence of marine mammals. Mean and standard deviation values for chlorophyll a and SST were taken from each bin along the trackline where marine mammals were encountered and not encountered. These values were selected from the 4 day MODIS composites for the day of survey effort and for days occurring 1 week, 2 weeks, and 4 weeks before and after the ship surveyed an area. Marine mammal sightings were also broken into two groups: 1) species generally believed to forage epipelagically, preying

on low trophic level organisms and 2) species that dive to forage in mesopelagic and bathypelagic depths, capturing higher trophic level prey.

Both epipelagic and deeper feeding marine mammals showed strong relationships to mean chlorophyll a at all spatial bins. A non-parametric Kolmogorov-Smirnov test found that the distribution of mean chlorophyll a concentrations at locations where surface and deep feeding cetaceans were sighted was most different and greater than the chlorophyll a at locations of non-sightings when no time lag was used at the 9 km^2 spatial bin. Moreover, differences in standard deviation values of chlorophyll a between bins containing marine mammal sightings and those of non-sightings were even more prominent than when mean chlorophyll a was used. The strong relationship between standard deviation of chlorophyll a and marine mammal sightings indicates that the change in chlorophyll at the surface is perhaps more important than the mean concentration of chlorophyll (i.e. standing stock of phytoplankton) in a location, and this relationship is likely indicative of the physical oceanographic features of areas where mammals were seen. Additionally, deep-feeders were found in generally warmer waters than non-sightings, whereas surface feeders were found within cooler waters. The shorter lags between surface chlorophyll and deep-feeding cetacean presence, in combination with the generally warmer waters where these deep-feeding animals were found, suggests that these species preferentially inhabit recently developed zones of divergence as compared to those cetaceans feeding nearer the surface. Overall, this study

finds that satellite ocean color imagery can usefully resolve relationships between marine mammals and their habitat at small spatial and temporal scales.

Introduction

In the Eastern Equatorial Pacific (EEP), strong surface and midwater currents create a unique regional habitat for marine mammals. The dominant wind-driven, surface current within the study area is the South Equatorial Current (SEC). Depending upon the longitude and the season, the SEC extends from about 25°S to 5°N and drives water from the South American coast westward across the Pacific.

The central SEC has a mass transport of just 17 Sv when integrated through the first 200 m. This transport is, however, highly variable with a range of 7-26 Sv (Fiedler et al., 1991). Near 3°N and 3°S average surface speeds within the two main 'lobes' of the SEC reach 50 cm/s. Along the equator, the SEC slows considerably, likely due to Ekman divergence and equatorial upwelling (Fiedler et al. 2006). The band of enhanced biological activity created by this divergence is another important oceanographic feature of the EEP.

The Equatorial Front (EF) lies just north of the equator, within the boundaries of the SEC (at about 2°N), and demarcates warm waters of the north, from cooler waters south of the equator (Palacios, 2004; Fiedler et al., 2006). Annual strengthening of both the SEC and EF during the second half of the year are the dominant physical forcings behind

SST and ocean color variance around the Galápagos Islands (Palacios, 2004), creating productive habitat for a large array of marine organisms. The EF may shift by as much as 200 km on 20-30 day time scales due to advection by tropical instability waves (TIWs) (Kessler, 2006). These shifts create a dynamic physical environment for organisms living along its periphery. For example, large associations of planktivorous seabirds can be observed within these frontal waters. However, fish and squid-consuming seabirds do not show any association with the front (Ballance et al., 2006).

West of the Galápagos, along the equator, from 140°W to at least as far eastward as 95°W, westward surface flow switches to an eastward flow. This change generally occurs during boreal spring (March/April) and is attributed to the shoaling of the Equatorial Undercurrent (EUC). The EUC is a thin subsurface jet confined largely to the thermocline layer. The core of the EUC is located at ~100m depth and has a mean temperature of about 13°C (Jones, 1973). Topographic upwelling of this current along the western side of the Galápagos Archipelago is likely responsible for a considerable portion of the nutrient-rich waters found there; it is the second dominant physical force influencing ocean color and SST variance within the archipelago (Palacios, 2004). The plume of phytoplankton growth that occurs on the western, upwelling side of the archipelago is highly variable on seasonal and intra-seasonal scales. Annual phase of surface chlorophyll concentration has two cycles within the archipelago. In the northern portion, chlorophyll peaks around austral fall (May), when the Panama Bight current is advecting color rich (phytoplankton or color dissolved organic matter) waters into the

Archipelago. Within the southern archipelago waters, chlorophyll peaks in August, during austral spring, when the strengthening southeast trade winds enhance equatorial upwelling (Palacios, 2004).

In some years, the EUC may flow as far eastward as Peru's coast and there is evidence to suggest that this high-salinity, high-oxygen water actually branches southward to feed the Peru Undercurrent. The Peru Undercurrent flows poleward along the continental coast.

Extending west of the Galápagos Islands is a feature known as the Equatorial Cold Tongue. Seasonal advection from the Peru Current (Humboldt Current) and equatorial upwelling drive much of this feature (Wyrtki, 1967; Fiedler and Talley, 2006). Tropical Instability Waves (TIWs) also distort the northern and southern fronts of the Equatorial Cold Tongue so that its shape constantly changes. It has seasonal temperature amplitudes of 1-3°C with coldest temperatures reached during September/October (Kessler, 2006). TIWs have periods of 20-40 days. Tropical Instability Vortices (TIVs) associated with the TIW perturbations display westward propagation speeds of 30-40 km per day (Willett et. al., 2006).

El Nino Southern Oscillation (ENSO) events also contribute to inter-annual variability. During ENSO events, the thermocline deepens by 5-10 m, particularly in the eastern Pacific along the equator. Even more noticeably influenced by ENSO events is the depth

of the mixed layer. Mean mixed layer depth during non-ENSO years above the equatorial and countercurrent thermocline ridges and within waters of the eastern boundary current is 10-20 m shallower than the thermocline. Possibly due to the greater influence of wind-forcing on shallower layers, ENSO variability is more focused on equatorial mixed layer depth than thermocline depth. Variability in surface temperatures associated with El Niño-Southern Oscillation (ENSO) is most pronounced along the equator and within eastern boundary current waters. The amplitude of this signal is ±1-2°C (Fiedler and Talley, 2006).

A review conducted by Balance et al. (2006) found that there was a varying response among sea birds to El Niño and La Niña events. During both these events there is generally a decrease in species richness among seabirds, though it is not known if this decrease is due to emigration or a failure to reproduce.

Common dolphins (*Delphinus delphis)* in 1986 also responded markedly to the ENSO cycle. From 1986 to 1988 the northward extension of cool upwelling water increased, which reduced the area of warm tropical surface water, thus expanding the range of preferred habitat for common dolphins. More so than any other dolphin species, common dolphin distribution fluctuated in phase with this ENSO event. Their population expanded with the widening of upwelling-modified waters and contracted when that habitat was replaced again by warm tropical waters (Ballance et al. 2006).

Oceanographic features of the EEP operate on spatial scales of hundreds to thousands of kilometers, and on seasonal, annual, and inter-annual time frames. However, marine mammals must locate foraging grounds on much smaller scales likely by processes happening over just days and tens of kilometers. The study of scale in marine ecology is an ongoing process. Sette (1955) considered the apparent disconnect between enhanced nutrient enrichment along equator at 120°W and the proven concentration of tuna along the equatorial 150°W parallel. Given mean westerly currents of the area, he estimated that a parcel of water would require approximately 75-150 days to travel between 120°W and 150°W and that therefore this must be the time frame necessary for biologically enriched waters to grow in 3 trophic levels of development. Blackburn et al. (1970) also estimated an approximate time lag of 4 months between peak chlorophyll and higher trophic level predators such as cephalopods.

Much of the early work regarding marine ecological scale had to be conducted using direct sampling methods, making frequent and sufficient coverage of a region difficult. Jaquet (1996) explored spatial and temporal scales influencing long-term sperm whale distribution in the tropical Pacific using satellite remote sensing data from the Coastal Zone Color Scanner (CZCS). She determined a positive relationship between sperm whale density and chlorophyll a concentration over broad scales of at least 900 km with a temporal resolution of at least a few months and confirmed a time and spatial lag between peak chlorophyll development and sperm whale density. However, the lag between chlorophyll a and sperm whale density could not be calculated due to the large

averaging necessary to composite useable satellite imagery. In the Gulf of Mexico, a lag of about 2 weeks between chlorophyll a development and sperm whale presence was estimated using smaller temporal and spatial averaging of satellite imagery from the MODIS instrument (4 day temporal averaging and 9 km^2 spatial binning) (O'Hern and Biggs, 2009).

The temporal lags considered by many studies assume large spatial averaging of biological data where bottom-up forcing of the food chain is responsible for the presence of larger predators. While increased biological activity can be measured over hundreds to thousands of kilometers the structure of that biomass may be what is ecologically important at the smaller scales (Jaquet et al. 1996; Mehlum et al., 1996; Smith, 2012). For example, aggregations of murres (*Uria spp.)* positively correlated with capelin (*Mallotus villosus*) density and patchiness at scales of 200-300 km, but only to capelin patchiness on scales of just 70 km. Additionally, whale sightings and satellite images from 1996 to 2000 in the Gulf of St. Lawrence, showed that the physical structuring of prey is important for large balaenopterid whales (Doniol-Valcroze et al., 2007). Rorquals were found to associate within close proximity of thermal frontal boundaries. Enhanced primary productivity generated by frontal boundaries did not explain the whales' association with frontal areas since frontal upwelling can vary spatially over a few days, yet whales could be found near the fronts over just single days. The authors emphasized that prey species for balaenopterids aggregate along the edges of frontal upwelling zones, which creates a more efficient foraging situation for the whales.

In order to estimate the spatial and temporal associations between cetaceans in the EEP and chlorophyll a variability at the surface, satellite ocean color data were composited for the smallest spatial and temporal scales feasible, given the limitations of orbital satellite data. These data were compared with the cetacean sightings made during five oceanographic cruises aboard the *B/I Orion*. Since surface chlorophyll is taken as a proxy for the variability of underlying physical conditions, time lags both before and after survey effort were used. A model developed by Oey and Zhang (2004) to explain the mixing of bottom nutrients into near-surface waters along cyclonic eddies helps explain why this is necessary. In 600-1000m of water, a subsurface jet is produced approximately 400-200m below the surface. Along the jet, just days after the cyclone and bottom topography begin frictional interaction, a mixing front is produced downstream. A week to two weeks later, intense frontal mixing occurs along the jet and ten days after mixing has begun, bottom nutrients are brought into shallower, more active layers. In this manner, nutrients may not enter the euphotic zone and create chlorophyll 'blooms' for 2-3 weeks *after* the front has developed. If cetaceans preferentially target the entrainment of higher organisms rather than new production, a chlorophyll signal might not be seen in the surface waters until after cetaceans have utilized the area. For this reason, symmetrical time lags of 1, 2 and 4 weeks were explored.

Methods

Marine Mammal Survey

The *B/I Orion* is an oceanographic vessel 70 m long and maintains average cruising speeds of 7-10 knots. During all five cruises the *B/I Orion* followed pre-determined North-South tracklines and East-West transit lines and made regular oceanographic measurements at CTD (Conductivity Temperature Depth) stations. The visual surveys were conducted from the flying bridge during all daylight hours (approximately 0600-1830 hrs) while the ship was underway, except for 30-minute meal times.

While observers actively searched for mammals, "on effort mode," 2-4 observers used Bushnell 7x50 binoculars to scan from the ship out to the horizon. A starboard observer scanned 90º right of the bow to 0º directly in front of the bow and a port side observer was responsible for 90º left of the bow through 0º in front of the bow. One observer was responsible for keeping notes on survey effort, environmental conditions and sightings. Sightings were only recorded while the ship was underway, under conditions of good visibility and full sunlight and with Beaufort states not > 5. Sighted animals were identified to lowest taxonomical level possible and observers estimated group size as well as noting the behavior of sighted groups.

Satellite and Sighting Data Processing

MODIS ocean color data from the Aqua satellite were downloaded from NASA's "Ocean Color" browser at http://oceancolor.gsfc.nasa.gov. Daily pass, level 2 data were batch ordered and downloaded from the ftp server for the chlorophyll a and daytime SST

(11 μm) products. The level 2 MODIS files have already undergone initial processing from the level 0 and 1 files, which contain the raw, backscattered radiance data.

An atmospheric correction algorithm is applied to pixels passing the quality control step to remove atmospheric scattering radiances from the total observed radiance. The water-leaving radiances obtained in this step are found in MODIS' bands 1-5. Bio-optical algorithms developed by the Ocean Biology Processing Group (OBGP) are applied to water-leaving radiances to calculate the geophysical properties, such as chlorophyll a concentrations. The chlorophyll a and 'SST' products were selected and data batch ordered for every day 30 days before and after survey effort for each cruise aboard the *B/I Orion*.

Chlorophyll a and SST data were batch processed using the SeaBatch 1.1 package written by Mike Brown, Cornell University (Brown, 2011). Slight modifications were made in order to composite imagery for a 4 day time period from its initial resolution of a 1000 m at 4 km^2, 9 km^2, and 36 km^2 spatial bins for the chlorophyll a. The 4 km^2 bin size was the smallest spatial composite used, because the 1 km bin size produced too little data for statistical analyses (due to too few pixels with valid quality control flagging). Each day of survey effort was considered a 'zero lag' day and represented by the 4 day temporal composite of the 4 days surrounding the day of survey effort. Composited imagery 1, 2, and 4 weeks before and after each day of survey effort represented the corresponding time lagged days. In this way, chlorophyll data were not

averaged over a temporal period, but represented discrete temporal lags from each day of survey effort. Since surface chlorophyll density is symptomatic of underlying oceanographic features, symmetrical time lags were used to assess whether cetacean presence preceded or followed surface chlorophyll build-up/entrainment.

Due to frequent cloud cover and other flagged pixels, SST data were only composited over 1 month time periods for each of the previously mentioned spatial bins. Due to this compositing, no time lag relationships were assessed between cetacean sightings and SST.

Pixels flagged by standard quality controls (atmospheric correction failure, land, sun glint, total radiance above knee, satellite zenith angle above limit, stray light contamination, clouds, coccolithophores, solar zenith angle above limit, low water-leaving radiance at 555 nm, chlorophyll a not calculable, questionable navigation, max iterations of NIR, chlorophyll out of range, epsilon out of range, navigation failure indicated in navigation flags, and insufficient neighboring pixels for epsilon calculation) were masked and not included in the binning of chlorophyll data, and so had no effect on the mean or standard deviation of the chlorophyll a calculated for each bin. Standard OBPG statistical products for the geophysical data within each bin include both arithmetic mean and standard deviation. For all other statistical analyses in this study, a geometric mean was utilized due to the general lognormal distribution of ocean color over the world's oceans (Campbell, 1995). However, OBGP determined during ground-

truthing for the SeaWIFS (Sea Viewing Wide Field-of-View Sensor) program that the arithmetic mean performed as well the geometric mean for the binning process (OBPG, 2007).

Chlorophyll and SST mean and standard deviation values were extracted from the newly created hdf files using a modified subroutine written by Chuanmin Hu of South Florida University (2004). Statistics were calculated using Matlab scripts written for this project.

Pseudoreplication was a concern when comparing locations of cetacean sightings and locations where no cetaceans were sighted (non-sightings). Each sighting was treated as a separate data point if observers clearly distinguished separate groups based on either distance traveled by the ship or behavior of the animals. Since the ship continued along straight tracklines without deviations to close on sighted groups of mammals, re-sightings of the same group were not generally a concern. Non-sightings were blocked into spatial bins approximately matching the spatial bin sizes of the MODIS data (i.e. chlorophyll of non-sighting points along the trackline were averaged every 4 km when the chlorophyll was extracted from MODIS files binned at 4 km^2). Since bins were created from points along the same tracklines, there were more bins at the 4 km^2 bin size and the fewest number of bins at the 36 km^2 size.

Analytical Processing

Cetacean sightings were considered as a whole and also divided into two groups: cetaceans of trophic levels less than 4 (as defined by Pauly et al., 1998) which also feed generally near the surface and cetaceans of trophic levels greater than 4 which often dive and forage within the mesopelagic and bathypelagic zones. These groups of surface and deep feeders were considered separately for analysis of their temporal correlation to surface chlorophyll. All of the baleen species and un-identified baleen whales were grouped as surface feeders. The diet of blue whales is perhaps the best studied for these species and is comprised mainly of euphausiids (Reilly and Thayer, 1990). While capable of deep dives, blue whales and other large baleen whales are generally believed to limit the depths of their dives during foraging (Aceveda-Gutiérrez et al., 2002). Recorded dives for blue whales within the California-Current system were between 100-200 m and 100m up to the surface (Croll et al., 1998).

Deep feeders included common dolphins (*Delphinus delphis)*, pilot whales (*Globicephala macrocephalus)*, un-identified stenellids (*Stenella sp.)*, pantropical spotted dolphins (*Stenella attenuata*), striped dolphins (*Stenella coeruleoalba)*, un-identified beaked whales (*Mesoplodon and Ziphius sp.)*, bottlenose dolphins (*Tursiops truncatus)* and sperm whales (*Physeter macrocephalus)*. These species are generally believed to rely heavily on cephalopods and other mesopelagic, nektonic species as prey (Clarke, 1980; Clarke, 1996; Smith and Whitehead, 2000; Santos et al., 2001; Praca and Gannier, 2007; Jefferson et al., 2008). Figure 13 illustrates the sighting locations of

cetaceans in these groupings. These categories of surface and deep-feeding cetaceans are somewhat approximate, since many of the species are opportunistic feeders and there is still much that is unknown about the feeding habits of cetaceans. For example, spotted and spinner dolphins are the most commonly sighted dolphin species associated with tuna-bird assemblages and may therefore feed on fish nearer the surface than the other odontocetes (Au and Perryman, 1985). These species were rare within my study area, however, and so grouping them as deep-feeders likely had little impact on the analysis.

Mean and standard deviation of chlorophyll a and SST from varying spatial and temporal bins gridded across the entire survey lines were tested for normality. Using the two-sample Kolmogorov-Smirnov test for normality with the Lilliefors significance correction, the null hypothesis for normality was rejected (binned chlorophyll data did not demonstrate a normal distribution). Log transformation of the chlorophyll data produced distributions more closely approximating normality (figures 9 and 10, Appendix B). Both parametric and non-parametric tests were used to compare chlorophyll from sighting and non-sighting locations. K-S tests separated the raw, non-transformed chlorophyll distributions of deep and surface feeding cetaceans from that of non-sighting locations. Pearson correlation coefficients for log-transformed chlorophyll tested potential correlations between sightings and observed chlorophyll at those same locations. For non-parametric tests, correlations with p-values of less than 0.05 were considered significant. For parametric tests, only correlations with p-values of less than

0.01 were considered significant, the lower p-value used for significance was meant to further guard against spurious correlations.

For the September/October cruises, chlorophyll data along the survey lines already demonstrated near-normal distributions and log transformations improved this fit (figure 9). For the April cruise, log transformations improved the fit, but even after transformation of the data, distributions still less nearly approximated normal distributions (figure 10) than the September/October chlorophyll data.

Results

Overall, four surveys were conducted during September/October or rainy season and 1 survey conducted during April or dry season. Along-track mean chlorophyll was highest during the September 2010 survey. This survey took place during a fairly strong La Niña, though Sea Surface Temperature (SST) along the cruise track was not noticeably lower than those of the three previous cruises. Only during the weak La Niña of 2011 did along-track SST fall statistically lower than that of the other cruises. Waters were warmest along the survey track during the April survey. The highest sighting rates for cetaceans (km/sighting) occurred during the coolest and warmest cruises.

Since cloud cover and other atmospheric interference prevented uniform color or SST satellite coverage, data from all four of the September/October cruises were combined

for statistical analyses of individual time lags. The descriptions below are also summarized in tables 10-17 and figures 11-12.

4 km^2 Chlorophyll and SST Mean

Overall, K-S tests indicated that the chlorophyll values at sighting locations were different and greater than non-sighting locations one week before and one month after the ship was present at these locations. Mean chlorophyll positively correlated with sighting locations at the day of ship survey through all time lags following ship survey, meaning chlorophyll was generally higher at sighting locations than non-sighting locations at the day of survey and 1, 2, and 4 weeks following survey effort.

The locations where surface feeding cetaceans were sighted positively correlated to mean chlorophyll with no time lag (0.3462, $p \leq 0.01$). At this time lag, locations of deep feeding cetaceans also demonstrated a chlorophyll distribution that was different from non-sighting locations as determined from the K-S test. Surface-feeding locations also had chlorophyll distributions that were different from and greater than non-sighting locations at the 1 month before time lag and the 1 week following sightings lag.

Locations where deep feeding cetaceans were sighted only displayed generally higher chlorophyll from that of non-sighting locations when no time lag was used.

At all time lags following the day of sightings, the K-S test indicated that chlorophyll distributions at locations where surface feeders were sighted versus locations where deep feeders were sighted were statistically different from each other. Chlorophyll levels at the locations of surface feeders were generally higher than those found at deep feeder locations.

Deep feeders were found in areas of higher SST (23°C) than non-sighting locations when all cruises were considered together. Conversely, surface feeders were found in slightly cooler waters, particularly during the fall cruises (22°C).

9 km^2 Chlorophyll and SST Mean

Overall, K-S tests indicated that chlorophyll at sighting locations was different and greater than non-sighting locations one month after the ship was present at these locations. Chlorophyll from this time lag correlated positively with sightings (0.2689, $p < 0.001$).

The K-S test indicated that mean chlorophyll at locations where surface feeding cetaceans were sighted was different from mean chlorophyll at non-sighting locations when no time lag was considered, a month before and after ship survey, and 1 week after ship survey. Mean chlorophyll with no time lag at these sighting locations demonstrated a positive correlation ($p \leq 0.009$).

K-S test results also showed that mean chlorophyll at locations of deep feeding cetaceans was different from mean chlorophyll at non-sighting locations when no time lag is used. Deep feeding sightings correlated positively to chlorophyll (0.2436, $p \leq 0.001$).

At all time lags following the day of sightings, the K-S test indicated that the distribution of chlorophyll at locations where surface feeders were sighted versus the distribution of chlorophyll at locations where deep feeders were sighted were statistically different from each other. However, only with a lag of 1 month following survey effort was mean chlorophyll at the locations of surface feeders statistically higher than mean chlorophyll at deep feeder locations at the 95% confidence interval.

Deep feeders were found in areas of higher SST (23.6°C) when all cruises were considered together, while surface feeders during combined cruises were found in slightly cooler waters (22.0°C).

36 km^2 Chlorophyll and SST Mean

When all sightings were grouped together, chlorophyll at sighting locations did not appear to differ from non-sighting locations. However, K-S tests found that chlorophyll at surface feeding cetacean locations was different and greater than non-sighting locations 2 and 4 weeks before and after ship survey.

No time lags demonstrated differences in the distributions of mean chlorophyll at locations where deep feeding cetaceans were sighted compared to non-sighting locations.

One month before and after and 1 week after ship survey, surface and deep feeding cetacean sighting locations differed in their mean chlorophyll distributions. Surface feeders were generally found in areas of locally higher chlorophyll when a time lag of 1 month following survey effort was used.

Deep feeders were found in areas of higher SST (23.7°C) when all cruises were considered together, while surface feeders cruises were found in slightly cooler waters (22.1°C).

4 km^2 Chlorophyll and SST STD

K-S test analysis indicated a difference in the chlorophyll STD within bins between all sighting and non-sighting locations for the zero time lag, a lag of 1 month before and after ship survey, and 1 week before and after ship survey. For all of these lags, the STD of chlorophyll was higher at sighting locations than non-sighting locations.

On the day of sightings, 1 week before and after survey, and 1 month before and after survey K-S tests showed that chlorophyll STD at sighting locations of surface feeders was different and greater than that of non-sighting locations.

Deep feeding cetaceans were sighted at locations of chlorophyll STD that was higher than the chlorophyll STD of bins at non-sighting locations when a time lag of 1 week preceding ship survey was considered. The standard deviation of chlorophyll did positively correlate with sightings of deep feeding cetaceans when no lag, and lags of 1 week and 1 month following sightings were used.

Chlorophyll at surface feeding and deep feeding sighting locations differed from one another when time lags of 1 week or 1 month following ship survey were used. At these time lags, mean chlorophyll was higher at locations of surface feeder sightings.

The STD of binned SST negatively correlated with sightings of deep feeders during the April cruise, meaning SST within sighting bins was more homogonous than those of non-sightings. During fall cruises, STD of SST positively correlated with sightings of surface feeders, meaning the SST within these bins displayed greater variability than the SST of non-sighting bins. This is the only bin for which STD of SST at deep feeder sighting locations was lower than that of non-sighting locations.

9 km^2 Chlorophyll and SST STD

Overall, sighting locations were different from non-sighting locations and positively correlated with chlorophyll STD at all time lags.

Surface feeding cetaceans were sighted at locations of chlorophyll STD that was different from and greater than non-sighting locations at time lags of no lag, 1 week before and after survey, 2 weeks after survey, and 1 month after survey, as indicated by the K-S test. Locations of surface feeders positively correlated with chlorophyll STD most strongly when no lag was considered.

Deep feeders were sighted at locations with distributions of chlorophyll STD than was statistically different from that of non-sighting locations at no lag and 1 week after survey. Correlations at this bin were stronger than most other comparisons at 0.3317 and 0.3136, respectively.

The K-S test indicated differences between chlorophyll STD at surface and deep feeding cetacean sighting locations 1 week and 1 month following ship survey. At these lags, chlorophyll was generally greater at locations of surface feeder sightings than deep feeder sightings.

The STD of binned SST negatively correlated with sightings of deep feeders during the April cruise, meaning SST within sighting bins was more homogonous than those of non-sightings. During fall cruises, STD of SST positively correlated with sightings of surface feeders, meaning the SST within these bins displayed greater variability than the SST of non-sighting bins. When all cruises were considered together, deep feeders displayed a positive correlations between their sighting locations and STD of SST. It

appears that STD of SST was generally higher at deep feeder sighting locations than non-sighting locations during the April cruise and lower during the fall cruises.

36 km^2 Chlorophyll and SST STD

Overall, sighting locations were in areas where chlorophyll STD was greater than non-sighting locations at a lag of 1 month following survey.

Chlorophyll STD at locations of surface feeder sightings was different from non-sighting chlorophyll STD for all time lags and positively correlated with chlorophyll STD. At all time lags, chlorophyll values positively correlated with locations of sightings.

Distribution of chlorophyll values at deep feeding cetacean locations differed from non-sighting locations at no lag, 1 weeks following ship survey, and 1 month before and after survey. Positive correlations between deep feeders and chlorophyll STD occurred 1 week before and after survey, 2 weeks after survey and 1 month before and after survey.

At two weeks before survey, 1 week after survey, and 1 month before and after survey, the chlorophyll STD of sighting bins differed between deep feeding and surface feeding cetacean locations.

The STD of binned SST negatively correlated with sightings of deep feeders during the April cruise, meaning SST within sighting bins was varied less than those of non-

sightings. During fall cruises, STD of SST positively correlated with sightings of surface feeders, meaning the SST within these bins displayed greater variability than the SST of non-sighting bins. For combined cruises, surface feeder STD of SST was higher than that of non-sighting locations. Deep feeder STD of SST was only slightly higher than non-sighting STD SST.

Discussion

Cetacean sighting rates were highest during the April 2009 cruise and the September 2011 cruise. In April, the EUC generally shoals toward the surface, causing a shift from westward surface water flow away from the islands to an eastward flow back toward Ecuador (Jones, 1973). SST is generally higher during this time of the year as is phytoplankton growth in the northern portion of the archipelago (Palacios, 2004). Observing conditions were also better during April than the September/October cruises. However the average sea state was only about half a point lower on the Beaufort scale in April than during the September-October cruises. Observing conditions alone likely did not account for the much higher sighting rate.

During September 2011, a weak La Niña was ending. SST was lowest along the cruise-track compared to all other cruises, though mean surface chlorophyll was not markedly different from any other year. Conversely, the previous year actually experienced a stronger La Niña with higher mean chlorophyll along the track-line, though cetacean sighting rates were much lower than that of 2011 and comparable to all other years.

Seasonal and inter-annual variations clearly influence the abundance and distribution of cetaceans within the EEP.

Johnston (2011) found that during ENSO neutral conditions the water column vertical temperature gradient limit that defines acceptable habitat for yellowfin tuna shoaled toward the surface and supported the formation of tuna-bird-dolphin assemblages. While this physical structuring of the water column provides suitable habitat for species such as the short-beaked common dolphin which feed within these assemblages, as well as other species benefiting from a shoaled thermocline, the assemblages are also easily detectable from a distance of several miles. Sighting rates were highest during ENSO neutral and weak La Niña states and it may be due to the shoaled thermocline and yellowfin tuna temperature gradient.

Locations of cetacean sightings generally demonstrated higher mean and standard deviation of surface chlorophyll than locations where no cetaceans were sighted. This pattern held true at 4 km^2, 9 km^2 and 36 km^2 spatial bins. These spatial bins are smaller than those used in many past studies and suggest that cetaceans respond to their environment at small spatial scales, and that these responses are measurable.

When all cetacean sightings are considered as a whole, that is both surface and deep feeding cetaceans from all five of the cruises, mean chlorophyll demonstrated a

significant positive correlation with cetacean sightings both 1 week preceding and 4 weeks following lags.

However, when the standard deviation of chlorophyll within bins was used rather than the mean chlorophyll density, locations of cetacean sightings differed more strongly from non-sighting locations at multiple time lags for both the 4 km^2 and 9 km^2 spatial bins. Sighting locations also demonstrated positive correlations with chlorophyll. At the largest spatial bin of 36 km^2, there were positive correlations between sightings and chlorophyll at all time lags. This pattern indicates that cetaceans as a whole are more sensitive to the variability in chlorophyll over relatively small areas (or the processes affecting that variability) than to the actual concentration of chlorophyll in the water.

Cetacean sightings were also broken into two groups, those animals feeding generally near the surface in the epipelagic zone and lower on the trophic scale (Balaenopterid whales) and those odontocetes that often feed deeper in the meso-and bathypelagic portions of the water column and higher on the trophic scale. Mean and standard deviation of chlorophyll differed between locations where these two groups were seen for all spatial bins at those time lags following survey effort (with the exception of 2 weeks following effort at the 36 km^2 spatial bin). On the day of survey effort, there appeared to be no difference in the chlorophyll values at locations where surface feeding cetaceans were seen versus locations of deep feeding cetacean sightings.

At the smallest spatial bins, locations of both surface feeding and deep feeding cetaceans displayed statistically significant differences in mean chlorophyll from the locations of non-sightings on the day of survey effort (no time lag). However, surface-feeding cetaceans were also found in locations where mean chlorophyll differed from that of non-sighting locations 1 week following survey effort at the 4 km^2 spatial bin. As the spatial bin was expanded from 4 to 9 and 36 km^2, differences in mean chlorophyll were also found 1 week after and 1 month before and following survey effort, at the same lags where surface and deep-feeding cetacean locations also differed in their mean chlorophyll values. Deep-feeding cetacean locations did not display any difference in mean chlorophyll from non-sighting locations at these time lags. In other words, surface-feeding cetaceans responded to mean chlorophyll over wider time-space scales than did deep-feeding cetaceans.

Surface-feeding cetaceans demonstrated a relationship to the standard deviation of chlorophyll over multiple time scales, at all spatial bins. At the 36 km^2 bin, locations of surface-feeding cetaceans and non-sightings differed in their chlorophyll at all time lags. This may be due to the widening spatial bins smearing the effects of smaller scale features operating over shorter time scales. It could also be a reflection of the generally persistent biological productivity of the areas where surface feeders were encountered. Figure 13 of surface-feeder versus deep-feeder sightings reveals that surface-feeding cetaceans were largely found within the productive waters adjacent to the Galápagos Islands and mainland coast.

Surface feeding cetaceans displayed the highest values for mean and standard deviation of chlorophyll at their sighting locations. Mean chlorophyll may lag and follow surface-feeder sightings by 4 weeks. High mean and standard deviation of chlorophyll did not lag deep-feeder sightings by more than 1 to 2 weeks and was most prevalent at the smallest spatial bins. Given that locations cetaceans showed stronger correlations and greater differences between non-sighting locations to standard deviation rather than mean chlorophyll concentration, it is likely that the physical properties of areas of frontal mixing may be more important than the actual quantity of phytoplankton and primary productivity of these areas.

The surface feeders were also found in cooler water with higher SST variability. Deep feeders, by contrast, were found in warmer waters than non-sighting locations. At a spatial bin of 4 km^2, waters where deep feeders were sighted displayed less variability of temperature than non-sighting locations. At the wider spatial bins, the variability of SST increased, indicating that frontal waters selected by deep feeders were affected by processes operating on scales smaller than the 9 km^2 bin.

One explanation for these patterns is that cetaceans are congregating near small oceanic fronts. Areas of high standard deviation in chlorophyll are a proxy for locations where physical features are causing abrupt changes in surface productivity, and cetacean presence did show a much stronger relationship to standard deviation of chlorophyll than density of chlorophyll. Locally enhanced variability in surface chlorophyll is usually the

result of strong frontal mixing driving nutrients into the photic zone and fertilizing phytoplankton growth (Eppley and Peterson, 1979; Denman and Gargett, 1983). These frontal areas can also act to entrain larger fish and squid prey (Okazaki et. al., 2002**;** Doniol-Volcroz et. al., 2007), which is beneficial to those cetaceans feeding by individual capture on higher trophic-level, actively swimming prey. Since statistically significant correlations can be found between surface chlorophyll and cetacean presence over the course of just a few days, it is likely that entrainment of prey, rather than trophic build-up, which requires several months of time, is the factor affecting presence.

Small and meso-scale fronts may be found at the peripheries of eddies, which are physically diverse and complicated features. Nel et al. (2001) found that grey-headed albatross (*Thalassarche chrysostoma)* preferred to forage over recently formed eddies, suggesting that the prey composition within the eddies changed over time. This might explain why deep-feeding cetaceans did not demonstrate the same temporal lags to surface chlorophyll as surface–feeders. A change in the prey available over the course of days and weeks (whether within an eddy or other frontal system that entrain prey species) could be due to foraging and grazing by other predators or by vertical changes in the prey field. For example, Wiebe (1982) found that slope-water euphausiids move downwards in decaying cold-core eddies, attempting to remain within their preferred habitat. Other species may undergo a similar process, forcing a trophic spatial shift within an eddy or front through time.

The warmer, less temperature variable surface waters where deep-feeders were most abundant suggest that these cetaceans target areas of convergence and possibly areas of anti-cyclonic rotation where convergence traps warm, surface waters. Surface feeders, by contrast, were usually found within cooler waters, more characteristic of divergence or areas of cyclonic rotation. Godo et al. (2012) demonstrated that surface biomass of plankton was lowest near the center of anti-cyclonic eddies and increased toward the periphery. Mid and deep-water biomass, however, was greatest near the eddy center and decreased, as does SST, toward the periphery. The Godo et al. data agree well with spatial and physical correlates of this study and support the supposition that deep and surface feeding cetaceans are both found in biologically productive but physically different waters.

Within the deep, equatorial waters of this study, the Coriolis force is small and topographic forcing does not impact surface water flows. Tropical Instability Waves (TIWs) that form on either side of the equatorial cold tongue generate Tropical Instability Vortices (TIVs). While these TIVs are generally found North of the Equator in the Pacific, the equatorward transport of water from these TIVs may heavily influence the productivity downstream. In the Atlantic, downstream transport of water was generally chlorophyll and nutrient poor (Willett et. al., 2006). However, as Bakun (2006) points out, larger planktonic and nektonic species entrapped within an eddy or near areas of divergence will also be transported downstream with those nutrient-poor waters, thereby enriching downstream waters for larger, predatory species.

Associated with these TIVs are mesoscale anticyclonic eddies that when observed along the equatorial Atlantic display radii of maximum velocity of less than 100 km (Foltz and Carton, 2004). While the physical mechanisms that generate areas of anticyclonic rotation along the equator are different than those that generate coastal and boundary current mesoscale eddies, oceanographic perturbations of surface waters still exist along the equator.

CHAPTER IV

OCEAN COLOR FRONTS

Summary

Biological activity in the deep ocean is driven by physical processes that operate over multiple spatial and temporal scales. Within this study's region extending from mainland Ecuador across the Galápagos Islands to 95°W longitude and bounded North and South at 4° latitude, a confluence of strong currents sustain high annual primary production. This production, however, is not evenly distributed. Large swaths of deep ocean far from the coast may produce more than an order of magnitude less primary biological activity than the more consistently upwelling areas (Palacios, 2004).

Instabilities in currents, oceanic eddies and other frontal systems are important physical structures in the open ocean. They are responsible for the mixing, advection, and general redistribution of water masses. Eddies may develop over days to weeks and span tens of kilometers (Godo et al., 2012). Cetaceans, as large apex predators, must efficiently utilize oceanographic features for foraging in the open seas. However, identifying the physical and biological properties of frontal systems exploited by cetaceans is complicated by the multitude of overlapping time and spatial scales. In this study, binned ocean color were used as a proxy for oceanic fronts. Within the study area, locations of elevated surface chlorophyll variability were identified as potential frontal systems.

Cetacean sightings and non-sightings along the cruise tracks for five separate surveys were compared to these potential color fronts. Overall, cetaceans were sighted closer than the average distance of binned non-sighting locations to the identified frontal areas.

Introduction

In areas of the open ocean where no bathymetric features exist to force topographic upwelling and no coastal inputs of nutrients lie nearby, vast expanses of biological deserts could form. The blue waters of the deep ocean, however, actually form a shifting patchwork of productivity. The pull from the winds on the ocean surface mixes oxygen into deeper, mid-level waters and tugs epipelagic nutrients up into the photic zone where they drive a cascade of biological activity. In the eastern tropical Pacific (ETP) these oceanic upwelling areas are located along the equatorial and counter-current divergences (Fiedler et al., 1991). These upwelling areas create large associations of seabirds and marine mammals along the boundaries of macro scale temperature fronts on scales of hundreds to thousands of kilometers (Guinet et al., 1997; Ballance et al., 2006; Bost et al., 2009).

Far from these areas of initial mixing and upwelling of nutrients, ocean currents entrain or encourage nektonic herbivores and predators downstream. Fiedler et al. (1991) found that much of the ETP waters are limited by nitrate, however where nitrate does exist, its utilization rate is lower than that of new production. This nutrient can persist within the

euphotic zone and be advected to nearby downwelling waters where it may continue to await biological uptake for over 200 days.

While enrichment and enhanced primary growth are important toward sustaining productive habitat over broad scales (Sette, 1955; Eppley and Peterson, 1979; Denman and Gargett, 1983; Fiedler et al., 1991), entrainment of higher organisms and creation of favorable foraging habitat are the more important factors impacting apex predators such as cetaceans (Sette, 1955; Mendes et al., 2002; Godo et al., 2012; Boersch-Supan et al., 2012). The entrainment of planktonic and nektonic species into a concentrated area obviously increases the local biomass, which means there is more prey available to larger predators. However, the physical features do more than just locally enhance the biomass. The turbulence within a frontal area also increases the encounter rate between predator and prey. This relationship has been especially well studied among planktonic organisms (Rothschild and Osborn, 1988; Sundby and Fossum, 1990; Mackenzie, 2000), but likely holds true for larger organisms as well. For example, salmon may become disoriented by currents, upwellings, or steep haloclines that result from strong tidal currents flowing over steep bathymetric gradients. Mendes et al., (2002) observed that individuals from a population of bottlenose dolphins off the coast of Northeast Scotland would orient themselves in relation to areas of current convergence in a tidal front within a deep, narrow channel.

MODIS ocean color data were used in this study to examine potential spatial relationships between cetaceans and frontal boundaries. Standard deviation of

chlorophyll within a spatial bin represented the amount of variability of chlorophyll within that area. An area of high variability or rapidly changing values of chlorophyll density was used as a proxy for a physical oceanographic frontal boundary. Given the strong correlations found in the previous chapter between standard deviation of chlorophyll and cetacean presence, chlorophyll data from the MODIS instrument were binned for the entire study area, not just the survey tracks. The study area was the same, all oceanic waters between the coast of mainland Ecuador and across the Galápagos Archipelago. Areas of high chlorophyll variability were identified and distances between cetacean sightings, non-sightings and frontal boundaries were measured.

Methods

Marine mammal sightings used in this analysis were the same as those used in Chapter 3. MODIS ocean color data from the Aqua satellite were initial processed in the same manner as described in Chapter 2. Spatially binned data were then temporally composited over a 30-day period in order to produce one or two files that encompassed the entire survey period of each cruise. These are the level 3 data. Standard OBPG statistical products for the geophysical data within each bin include both arithmetic mean and standard deviation. For all other statistical analyses in this study, a geometric mean was utilized due to the general lognormal distribution of ocean color over the world's oceans (Campbell, 1995). However, OBGP determined during ground-truthing for the SeaWIFS (Sea Viewing Wide Field-of-View Sensor) program that the arithmetic mean performed as well the geometric mean for the binning process.

The study region was defined as an area extending from the coastline of mainland Ecuador at 79°W through 95°W and 4°N to 4°S. The study region was gridded at every tenth of a degree and chlorophyll data were extracted at each grid point from the binned, monthly composited MODIS data using a modified subroutine written by Chuanmin Hu of South Florida University (2004).

Chlorophyll data were also extracted for non-sighting and sighting locations along the respective cruise tracks. Pseudoreplication was a concern for these non-sighting and sighting locations. Each sighting was treated as a separate data point if observers clearly distinguished separate groups based on either distance traveled by the ship or behavior of the animals. Non-sightings were blocked at spatial bins approximately matching the spatial bin sizes of the MODIS data (i.e. non-sighting points along the trackline were averaged every 4 km when the chlorophyll was extracted from MODIS files binned at 4 km^2).

The standard deviation of chlorophyll within each bin was utilized rather than the mean chlorophyll concentration. A high standard deviation of chlorophyll within a bin represents high variability of chlorophyll within that bin and is therefore used as a proxy for a frontal area. A geometric mean of all standard deviations of chlorophyll a calculated from each of the bins across the study region was calculated for each MODIS composite. Each bin with a standard deviation of chlorophyll that was greater than 1

standard deviation from the region's geometric mean standard deviation was flagged as a potential frontal location.

Modified programs in IDL transcribed from Fortran programs written by Dr. Matthew Howard and Dr. Steven DiMarco were used to calculate the distance between identified frontal locations and cruise track locations. The minimum distance between the chlorophyll front and each cruise track location was then identified.

Results

The distance between cetacean sightings and identified color fronts was on average smaller than the distance between non-sighting locations and color fronts (figures 19-21, Appendix C). For the 4 km^2 binned data, the September-October 2009 survey was the only survey for which mean distance between sighting locations and fronts was not significantly less than the mean distances between non-sightings and fronts (figure 19). For the 9 km^2 binned data, results were similar, although now in September 2011 as well as in September 2009, the two metrics were not significantly different (figure 20). At the 36 km^2 bin, mean distance between cetaceans and fronts was seldom significantly less than the distance non-sighting locations to fronts (figure 21), so overall cetaceans were closer to color fronts binned at 4 and 9 km^2 than were non-sighting locations. However, the strongest correlation between cetacean sightings and frontal presence occurred for surface-feeding cetaceans at the 36 km^2 bin (table 18). On average, cetaceans were about 40-70 km away from the nearest front, when color was binned at 4 km^2. Given this mean

distance, differences between cetacean sightings and non-sightings and the nearest 36 km^2 binned front are not expected to be great. This bin size appears to fall at the cusp of the scale at which cetaceans are responding to frontal boundaries. Figures 24-28 depict sightings overlaid on frontal locations within the study area for each cruise.

Comparing and contrasting epipelagic versus meso- and bathypelagic foragers, surface feeding cetaceans exhibited a significant negative correlation to distance from color fronts at all spatial bins. The strength of the correlation increased with increasing bin size. However, deep feeding cetaceans did not display a significant relationship to the distance between sighting and frontal locations at any spatial scale (Table 18). This lack of a relationship between deep feeders and monthly composited color data is not surprising though, given the lack of relationship between deep diving cetaceans and ocean color at the wider spatial and temporal scales analyzed in Chapter 3.

Interestingly, the group size of cetaceans sighted along the cruise track also displayed a weak linear relationship to color front locations (figures 22-23). Larger groups of animals appear to cluster more closely near the fronts, though a lack of large group sightings prohibited a more quantitative analysis.

Discussion

Small and meso-scale frontal systems are important habitat for cetaceans in the open ocean. They create efficient and productive foraging grounds for large, apex predators, which must consume large quantities of food, often exploiting only the densest foraging grounds (Piatt and Methveb, 1992; Croll et al., 1998; Griffin, 1999). However, not all cetaceans utilize the frontal areas in the same manner. As seen in the previous chapter, spatial and temporal lags vary between groups of cetaceans, depending upon where on the trophic scale and water column those cetaceans feed. In this analysis we can already see that our spatial and temporal scales are not small enough to resolve the habitat preferences of the deeper-diving cetaceans.

With the exception of 2009, cetaceans were encountered about 38-75 km from the nearest color front. This explains why the 4 and 9 km^2 spatial bins were the most useful for this analysis, as the 36 km^2 bin nearly matched the scale at which cetaceans associate with color fronts. This result is important for future work regarding habitat analysis within the EEP. While monthly time scales may be appropriate for some baleen species, spatial scales must be kept small.

The relatively wider scales on which surface feeders associate with color fronts suggests that they are locating habitat that is persistently productive over at least tens of kilometers and several weeks. By contrast, deep divers are likely more mobile in their

foraging and habitat selection, given the smaller scales on which they associate with enhanced ocean color variability.

Larger groups of cetaceans may be especially dependent on strong frontal mixing and entrainment in order to locate sufficiently abundant and densely distributed prey. When the prey field becomes too thin or patchy, large associations of cetaceans may need to split apart for periods of time in order to forage more effectively. Adjustments to social associations can have significant effects on highly mobile species with close social ties (Whitehead, 1996; Whitehead and Rendell, 2004).

It is not clear why cetaceans in 2009 displayed such a departure from other years in terms of their relative associations with frontal areas. September 2009 did fall at the end of an El Niño, and warm waters from the ENSO event could have washed out some of the physical structuring of the mid-level and surface depths as the thermocline and mixed layers deepened. Cetaceans may also use regional migration as a means of compensating for the rapid change in habitat brought on by an ENSO event. During these events cetacean distributions do change and this is likely the result of alternate foraging strategies (Benson et al., 2002).

In the future, smaller bin sizes for chlorophyll data will need to be used. Cetaceans are clearly utilizing frontal systems over small scales. Hydrographic data, collected at finer spatial scales, would also be useful in order to characterize the vertical structure of the

oceanographic features where cetaceans are sighted. These measurements would need to be made at more frequent intervals than every degree of latitude (as is the hydrographic sampling regime on *B/I Orion* cruises). More challenging to obtain than sufficient spatial sampling will be the temporal resolution of the data. In Chapter 3, associations between deep feeders and enhanced ocean color variability could be seen at spatial scales of 4-36 km, however it appears from the data collected that these associations are strongest with minimal time lag. Even sampling hydrographically every month may be too infrequent. It is this issue of temporal resolution that makes remote sensing of the ocean surface so appealing.

CHAPTER V

SUMMARY AND CONCLUSIONS

The cetacean population within waters adjacent to Ecuador and the Galápagos Archipelago numbers at least 282,253 and is inter-annually persistent. A wide range of both resident and migratory species makes use of this portion of the Eastern Equatorial Pacific (EEP). Common and striped dolphins were the two most commonly sighted species, although blue whales, Bryde's whales, sperm whales, pilot whales, bottlenose dolphins, as well as other species were also identified. The highest sighting rates (sightings per kilometer of survey effort) occurred during the April 2009 and September 2011 cruises, suggesting seasonal and ENSO cycling may affect the abundance or distribution of cetaceans in this region. Three other September-October cruises had similarly lower sighting rates.

Given the needs of marine resource management, greater attention must be paid to the scale at which oceanographic data are collected for management purposes and, of course, the manner in which those data are interpreted. The group of cetaceans defined as deep feeding cetaceans in this study associated with surface chlorophyll concentration, and more importantly, variability on scales of 4 – 36 km^2 and just days to weeks of time. This group displayed a stronger relationship to the standard deviation or variability of surface chlorophyll than to the average concentration of surface chlorophyll and while this association was strong, it was very much time dependent.

Monthly composited MODIS ocean color data were already at a temporal scale too wide to resolve any relationship between cetacean presence and the nearest color front. Future studies in the EEP will need to use remote sensing data that are collected from beneath cloud level or utilize model output to further explore the relationship between color fronts and deep feeding cetaceans.

Epipelagic cetaceans grouped as surface feeders, conversely, were found to associate with both surface chlorophyll concentration and variability at all spatial and temporal scales examined. Surface feeding cetaceans were on most cruises located within 38-75 km of the nearest ocean color front. Additionally, monthly composited sea surface temperature (SST) data revealed that mean SST was generally cooler at locations of surface feeder sightings than deep feeder sightings or non-sightings. The close proximity of ocean color fronts to surface feeder sightings relative to locations of non-sightings, cool temperatures, and high chlorophyll concentration and variability suggest that these animals target upwelling areas that are both spatially and temporally persistent.

The smaller spatial and temporal discontinuity between surface chlorophyll fronts and deep feeding cetaceans was somewhat surprising. Most previous studies suggested that there should be some lag between surface demonstration of a front and either the lateral and vertical transport of productivity created by the front or a vertical displacement as the front slants from the surface down to depth. However, deep feeders in this study did not appear to lag surface chlorophyll, at least not when the data were composited over

wide temporal scales. While chlorophyll variability was not as high as that found at surface feeder locations, chlorophyll variability at deep feeder locations did peak at 4 km^2 spatial bin and 1 to 2 week time lag. This lag may indicate some discontinuity between surface demonstration and frontal realization at depth. Deep feeders were also generally encountered in the warmer waters more characteristic of convergent zones and anti-cyclonic eddy rotation. This finding was also surprising, given that common dolphins were included in this group and are generally believed to favor upwelling-modified waters.

In conclusion, while both surface and deep feeding cetaceans were present in areas of locally elevated surface chlorophyll, the underlying physical structure of these areas was not the same. Future surveys that incorporate high resolution hydrographic sampling, coupled with remote sensing tools and tracking of individual cetaceans, should be able to determine the underlying physical conditions on a species by species basis.

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APPENDIX A

Table 1. Summary of surveys conducted in the study area from 1999-2011 used to estimate cetacean abundance. Number of Sightings = number of cetacean groups sighted; *Jordan and McArthur* are the NOAA Ships *David Starr Jordan and McArthur II*. *Orion* is the Ecuadorian Navy research vessel, *B/I Orion*. Dates, kilometers of survey effort within the study area and sightings from within the study area are summarized below.

Survey Years	Dates of Effort within Survey Area	Ship Name	Kilometers Surveyed	Number of Sightings	Kilometers/ Sighting
1999	12-Oct; 18-Oct; 8-Nov - 10-Nov	*Jordan*	709	57	12.4
2000	6-Oct - 10-Oct; 5-Nov - 9-Nov	*McArthur II*	1,626	37	43.9
2003	10-Oct - 12-Oct; 7-Nov - 9-Nov	*McArthur II*	789	36	21.9
2001	17-Sept - 8-Oct	*Orion*	1,903	30	63.5
2008	23-Sept 23 - 10-Oct	*Orion*	2,396	34	70.5
2009	7-Oct - 30-Oct	*Orion*	2,552	42	60.8
2010	25-Sept - 9-Oct	*Orion*	2,111	35	60.3
2011	25-Sept - 9-Oct	*Orion*	2,146	46	46.7

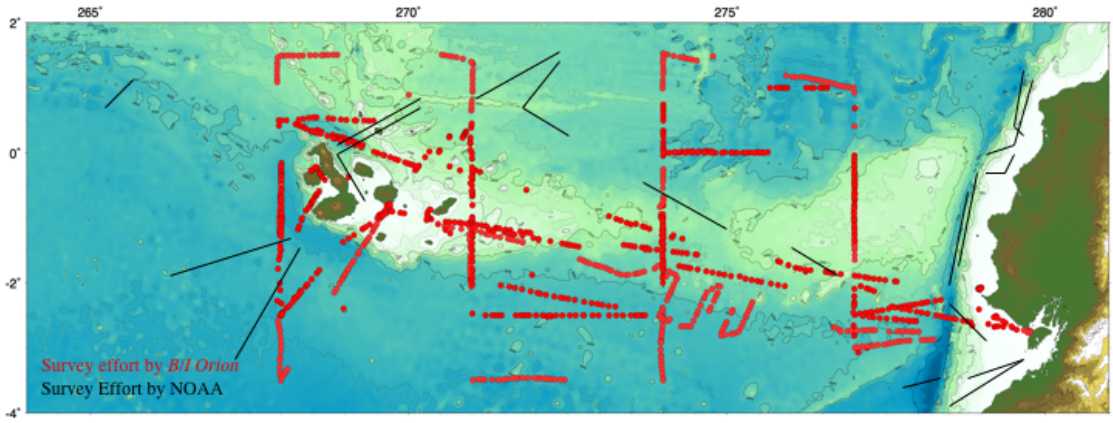


Figure 1. Survey effort tracklines for surveys aboard the *B/I Orion* and surveys conducted by NOAA SWFSC STAR program.

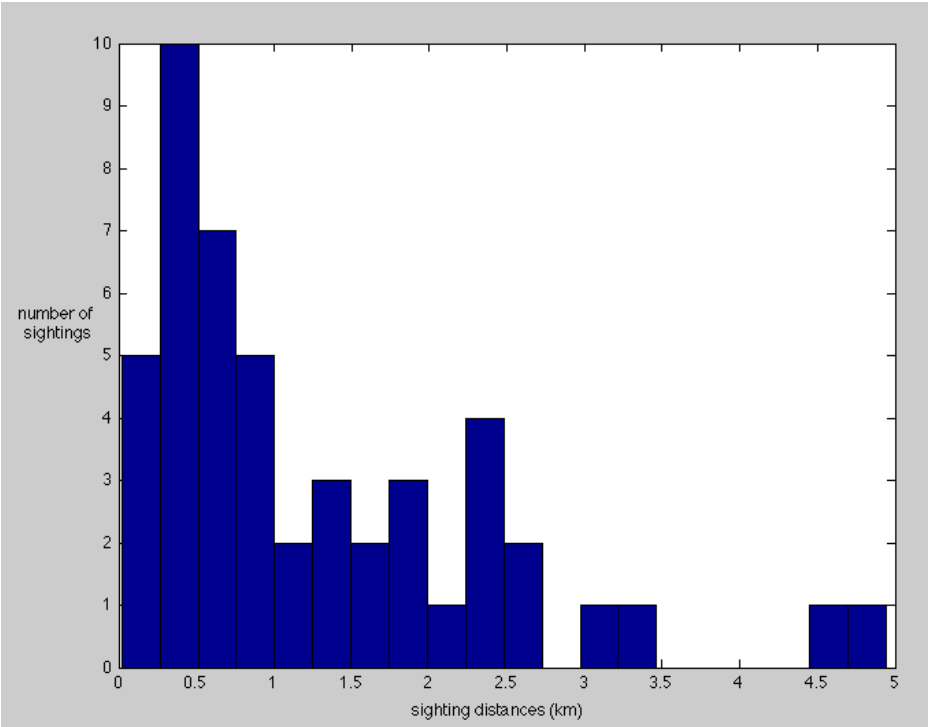


Figure 2. Histogram of initial sighting distances using fifteen distance categories. Distances are perpendicular distances measured in km between the trackline and initial sighting location of a cetacean. Sighting distances were measured during 2008 and 2011.

Table 2. Shape and scale parameters were tested for each model. $\sigma_{1\text{-}4}$ denote the scale parameters and b the shape parameters.

σ_1	σ_2	σ_3	σ_4
0.7631	0.7071	0.6934	0.7248
b 1	b 2	b 3	b 4
1.5	2	3	5

Table 3. Akaike's Information Criteria (AIC) for each function tested to model the detection function (g(x)). The shape and scale parameters are denoted by θ and b.

Model	AIC	Δ AIC	relative likelihoods	AIC weights
hazard-rate σ_1, b1	7.2103	1.6494	0.4384	0.0771
hazard-rate σ_2, b2	7.2296	1.6687	0.4341	0.0763
hazard-rate σ_3, b3	7.2379	1.677	0.4323	0.076
hazard-rate σ_4, b4	7.2296	1.6687	0.4342	0.0763
half-normal σ_1	5.5609	0	1	0.1758
half-normal σ_2	5.5963	0.0355	0.9824	0.1727
half-normal σ_3	5.6048	0.0439	0.9783	0.172
half-normal σ_4	5.5853	0.0244	0.9879	0.1737

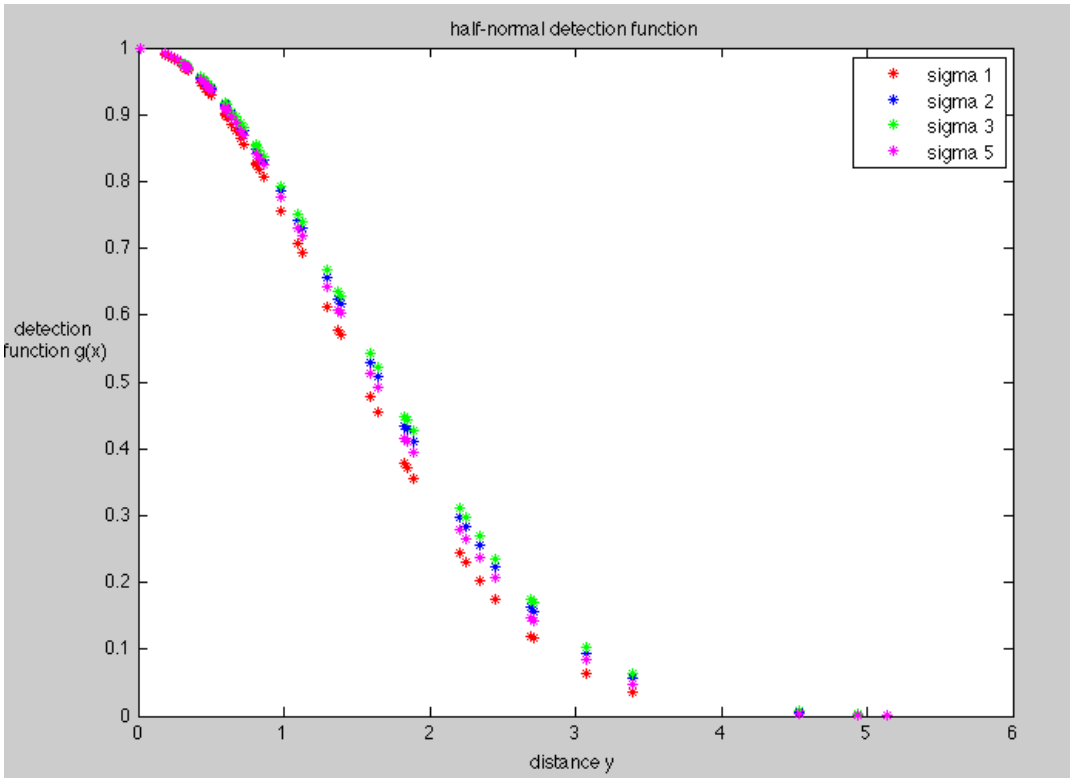


Figure 3. Plots of the half-normal detection function using five different values of the scale parameter, σ. Perpendicular distances versus number of sightings span the range of the actual sightings dataset.

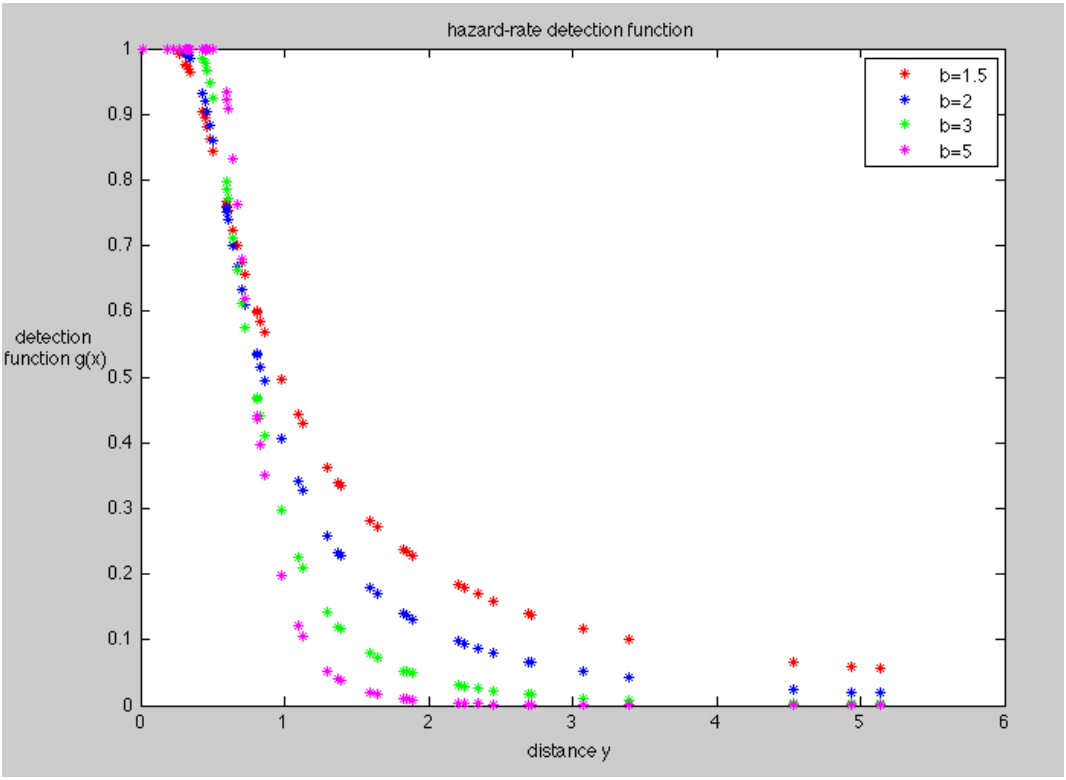


Figure 4. Plots of the hazard-rate detection function using five different values of the scale parameter, σ and shape parameter, b. Perpendicular distances versus number of sightings span the range of the actual sightings dataset.

Table 4. Probability density function for each main category for which an abundance estimate was made. The 95% confidence interval is denoted by 'lwr95' and 'upr95.'

Cetacean	*f*(0)	Number of Sightings within study area	Effective half strip width (km)	standard error *f* (0)	lwr95	upr95
Delphinus delphis 1999	0.303	14	3.3	0.0300	0.267	0.386
Delphinus delphis 2000	0.238	7	3.5	0.0170	0.203	0.275
Delphinus delphis 2003	0.319	7	3.0	0.0360	0.249	0.382
Stenella coeruleoalba 1999	0.343	12	3.5	0.0190	0.310	0.388
Stenella coeruleoalba 2000	0.369	5	2.8	0.0270	0.325	0.432
Stenella coeruleoalba 2003	0.357	7	2.7	0.0360	0.280	0.422
General Cetacean, NOAA 1999	0.347	58	2.9	0.0003	0.346	0.347
General Cetacean, NOAA 2000	0.336	37	4.2	0.0003	0.336	0.337
General Cetacean, NOAA 2003	0.319	36	3.1	0.0002	0.319	0.320
General Cetacean, *Orion*	1.28	79	0.78	0.1781	0.9298	1.6278

Table 5. Abundance estimates for cetaceans inside the study area using pooled sightings data from both *B/I Orion* and NOAA cruises. Abundance estimates for 'All species,' short-beaked common dolphins, and striped dolphins utilized the pooled dataset. GNR is the Galápagos National Reserve.

Statistics	All species of Cetaceans	Deep Off-shore Cetaceans 89°W - 82°W	GNR Cetaceans 89°W - 92°W; 1°N – 1.5°S	Short-beaked common dolphin	Striped dolphin
Abundance	282,253	77,703	53,739	133,021	38,271
Standard Error	43,565	12,911	25,112	20,323	5,184
lower 95% CI	196,864	52,396	45,197	58,554	19,443
upper 95% CI	367,640	103,010	102,960	138,221	39,766

Table 6. Abundance estimates for cetaceans inside study area with data separated by sources.

Statistics	All cetaceans using only NOAA sighting data	All cetaceans using only Orion sighting data	Short-beaked common dolphin with NOAA data	Striped dolphin with NOAA data
Abundance	387,290	252,706	255,018	67,111
Standard Error	66,926	77,692	69,694	14,360
lower 95% CI	256,110	113,227	118,420	38,967
upper 95% CI	518,460	417,781	391,623	95,257

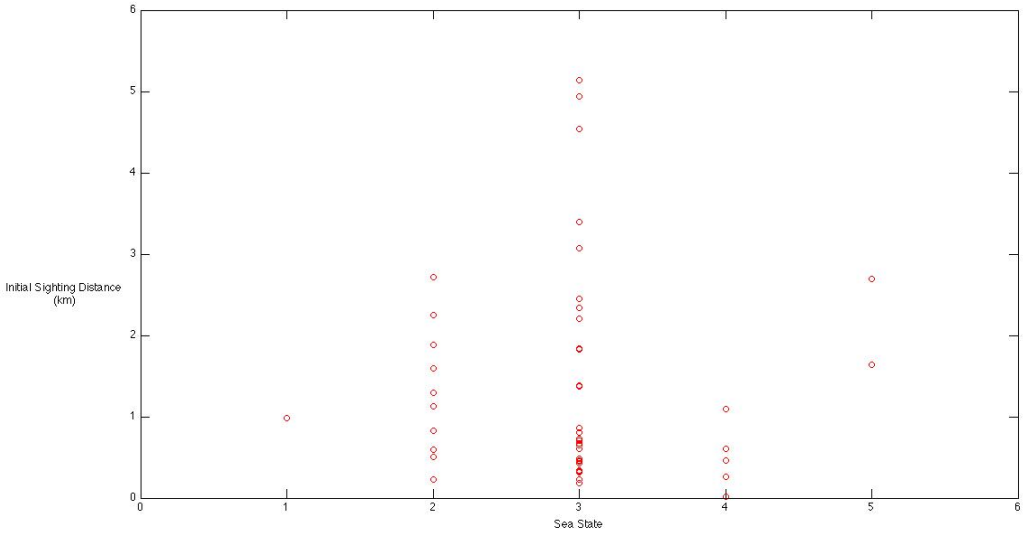


Figure 5. Sea state versus initial sighting distance (*Orion* cruises)

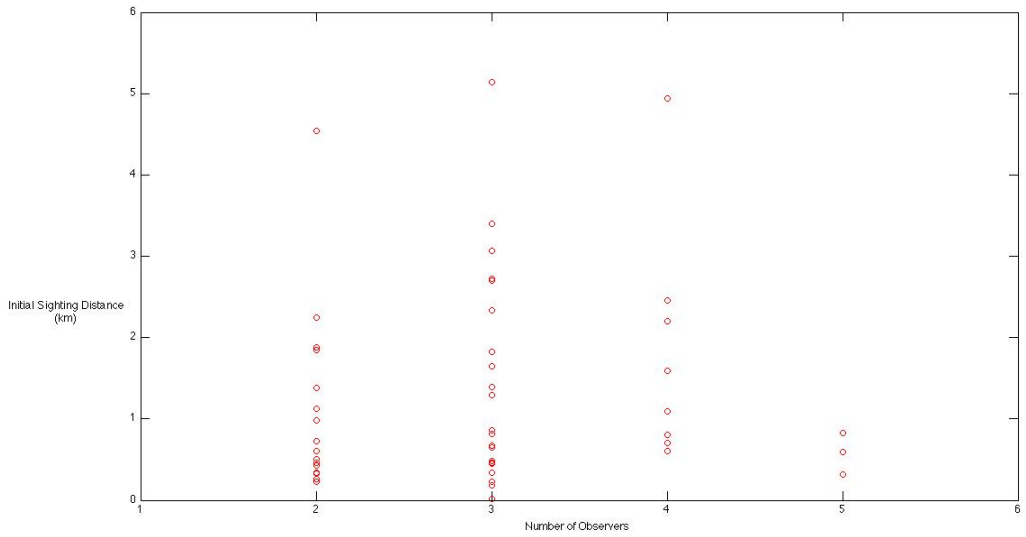


Figure 6. Number of Observers versus initial sighting distances of cetaceans (*Orion* cruises)

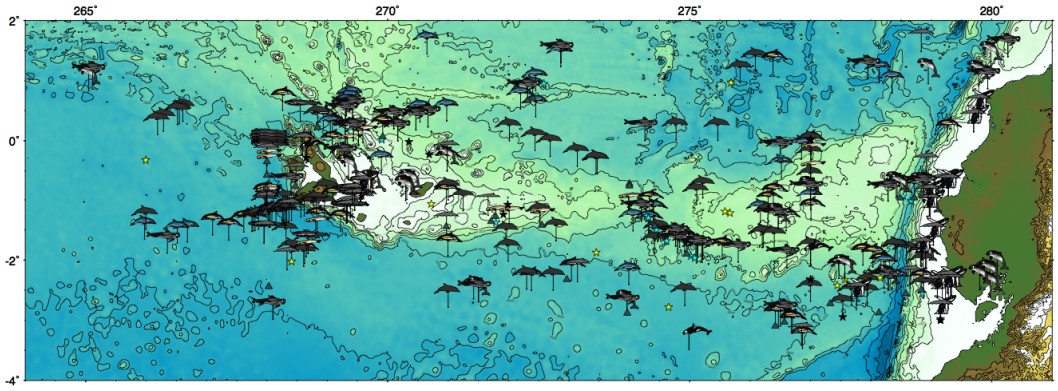


Figure 7. Cetacean sightings from surveys aboard the *B/I Orion* and NOAA STAR cruises, 1999-2010

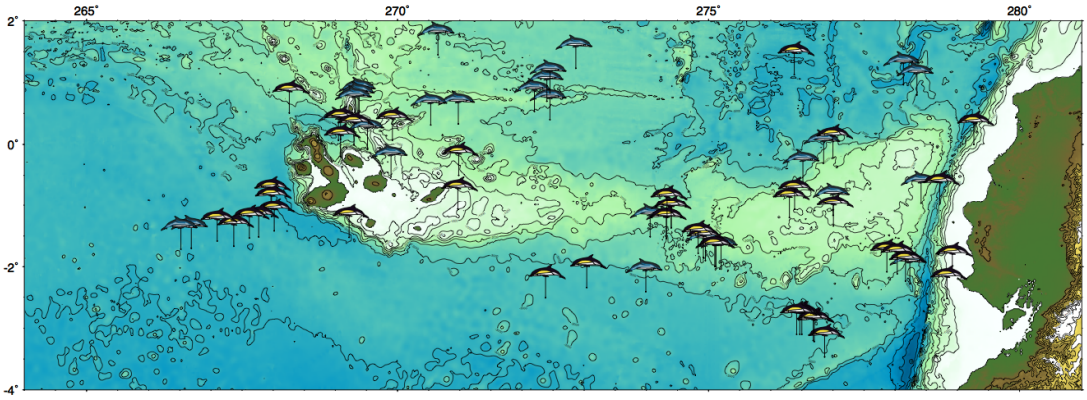


Figure 8. Striped dolphin and short-beaked common dolphin sightings from surveys aboard the *B/I Orion* and NOAA STAR cruises, 1999-2011

APPENDIX B

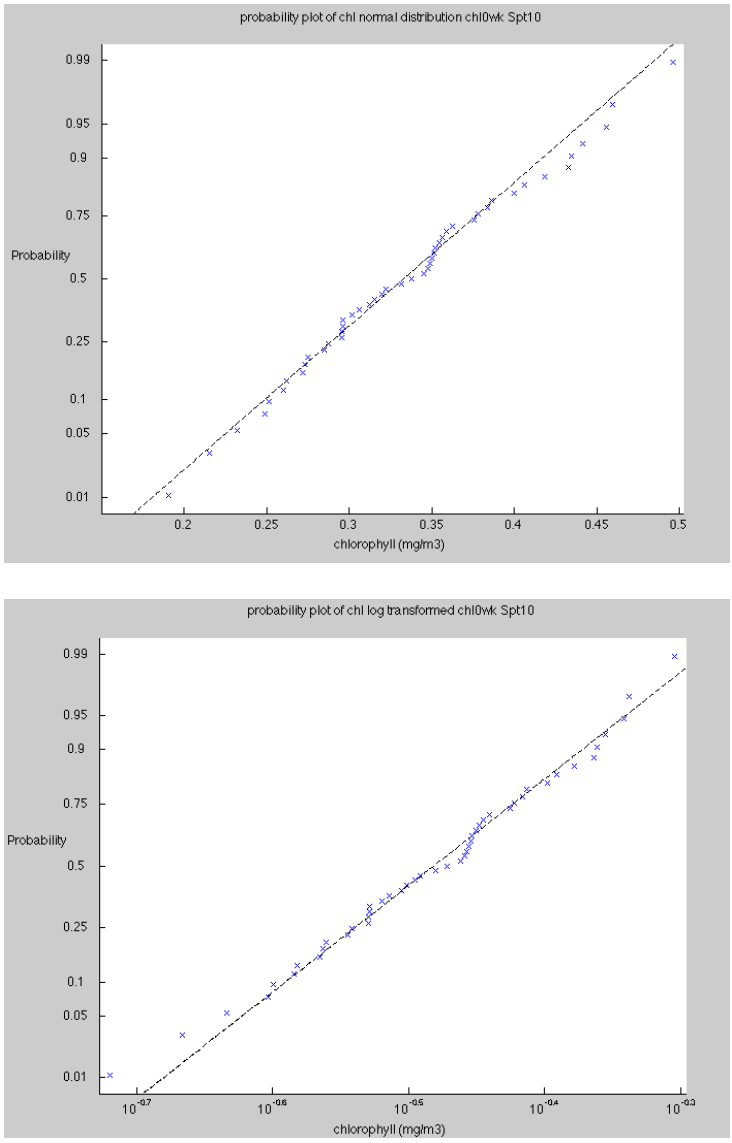


Figure 9: Along-trackline chlorophyll, 4 km^2 spatial bin during September/October 2010. Comparison of a lognormal probability distribution with the distribution of chlorophyll a. visualization of how nearly the transformed chlorophyll data conform to a normal distribution.

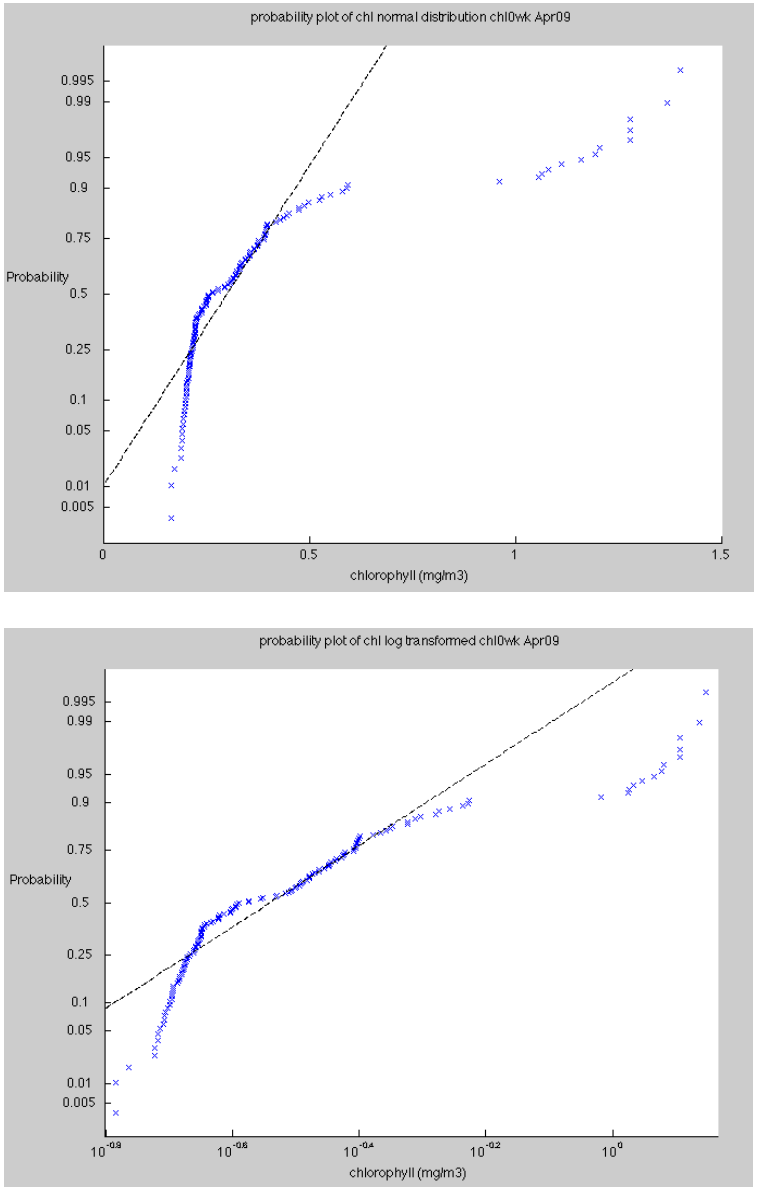


Figure 10: Along-trackline chlorophyll, 4 km^2 spatial bin during April 2009. Comparison of a lognormal probability distribution with the distribution of chlorophyll a, visualization of how nearly the transformed chlorophyll data conform to a normal distribution.

Table 7. Summary of lilliefors test of normality for chlorophyll a at the 4 km^2 spatial bin

time lag	n sightings	n non-sightings	h value lillie test	p value lillie test	lillie h value, log transformed	lillie p-value, log transformed
April 2009 no lag	76	68	1	0.001	1	0.001
April 2009 1 wk before	66	67	1	0.001	1	0.001
April 2009 2 weeks before	77	69	1	0.001	1	0.001
April 2009 4 weeks before	76	68	1	0.001	1	0.001
April 2009 1 week after	75	69	1	0.001	1	0.001
April 2009 2 weeks after	73	68	1	0.001	1	0.001
April 2009 4 weeks after	28	52	1	0.001	1	0.001
Sept/Oct no lag	47	218	1	0.001	1	0.001
Sept/Oct 1 wk before	51	202	1	0.001	1	0.001
Sept/Oct 2 weeks before	55	205	1	0.001	1	0.001
Sept/Oct 4 weeks before	58	220	1	0.001	0	0.5
Sept/Oct 1 week after	62	260	1	0.001	1	0.001
Sept/Oct 2 weeks after	62	250	1	0.001	1	0.001
Sept/Oct 4 weeks after	81	335	1	0.001	1	0.001
All cruises no lag	123	286	1	0.001	1	0.001
All cruises 1 wk before	117	269	1	0.001	1	0.001
All cruises 2 weeks before	132	274	1	0.001	1	0.001
All cruises 4 weeks before	134	288	1	0.001	1	0.00201
All cruises 1 week after	137	329	1	0.001	1	0.001
All cruises 2 weeks after	135	318	1	0.001	1	0.001
All cruises 4 weeks after	109	387	1	0.001	1	0.001

Table 8. Summary of lilliefors test of normality for chlorophyll a at the 9 km^2 spatial bin

time lag	n sightings	n non-sightings	h value lillie test	p value lillie test	lillie h value, log transformed	lillie p-value, log transformed
April 2009 no lag	76	29	1	0.001	1	0.001
April 2009 1 wk before	65	26	1	0.001	1	0.001
April 2009 2 weeks before	76	26	1	0.001	1	0.001
April 2009 4 weeks before	76	25	1	0.001	1	0.001
April 2009 1 week after	77	26	1	0.001	1	0.001
April 2009 2 weeks after	74	27	1	0.001	1	0.001
April 2009 4 weeks after	29	21	1	0.001	1	0.001
Sept/Oct no lag	50	122	1	0.001	1	0.03176
Sept/Oct 1 wk before	55	134	1	0.001	1	0.00229
Sept/Oct 2 weeks before	64	142	1	0.001	1	0.001
Sept/Oct 4 weeks before	66	153	1	0.001	0	0.17218
Sept/Oct 1 week after	72	162	1	0.001	1	0.001
Sept/Oct 2 weeks after	72	159	1	0.001	1	0.001
Sept/Oct 4 weeks after	90	211	1	0.001	1	0.001
All cruises no lag	126	151	1	0.001	1	0.001
All cruises 1 wk before	120	160	1	0.001	1	0.001
All cruises 2 weeks before	140	168	1	0.001	1	0.001
All cruises 4 weeks before	142	178	1	0.001	1	0.001
All cruises 1 week after	149	188	1	0.001	1	0.001
All cruises 2 weeks after	146	186	1	0.001	1	0.001
All cruises 4 weeks after	119	232	1	0.001	1	0.001

Table 9. Summary of lilliefors test of normality for chlorophyll a at the 36 km^2 spatial bin

time lag	n sightings	n non-sightings	h value lillie test	p value lillie test	lillie h value, log transformed	lillie p-value, log transformed
April 2009 no lag	76	29	1	0.001	1	0.001
April 2009 1 wk before	65	26	1	0.001	1	0.001
April 2009 2 weeks before	76	26	1	0.001	1	0.001
April 2009 4 weeks before	76	25	1	0.001	1	0.001
April 2009 1 week after	77	26	1	0.001	1	0.001
April 2009 2 weeks after	74	27	1	0.001	1	0.001
April 2009 4 weeks after	29	21	1	0.001	1	0.001
Sept/Oct no lag	50	122	1	0.001	1	0.03176
Sept/Oct 1 wk before	55	134	1	0.001	1	0.00229
Sept/Oct 2 weeks before	64	142	1	0.001	1	0.001
Sept/Oct 4 weeks before	66	153	1	0.001	0	0.17218
Sept/Oct 1 week after	72	162	1	0.001	1	0.001
Sept/Oct 2 weeks after	72	159	1	0.001	1	0.001
Sept/Oct 4 weeks after	90	211	1	0.001	1	0.001
All cruises no lag	126	151	1	0.001	1	0.001
All cruises 1 wk before	120	160	1	0.001	1	0.001
All cruises 2 weeks before	140	168	1	0.001	1	0.001
All cruises 4 weeks before	142	178	1	0.001	1	0.001
All cruises 1 week after	149	188	1	0.001	1	0.001
All cruises 2 weeks after	146	186	1	0.001	1	0.001
All cruises 4 weeks after	119	232	1	0.001	1	0.001

Table 10. Summary of survey effort, sightings and conditions along the tracklines for each cruise aboard the *B/I Orion*, 2008-2011.

Survey Years	Dates of Effort within Survey Area	Kilometers Surveyed	Number of Sightings	Km/ Sighting	ENSO state	Along-track Mean CHL mg/m3	Along-track Mean SST °C
2008	23 Sep – 10 Oct	2,396	34	70.5	Normal	0.2652	22.0
2009	7 Oct – 30 Oct	2,552	42	60.8	weak El Niño	0.2553	22.5
2010	25 Sep – 9 Oct	2,111	35	60.3	Strong La Niña	0.3504	21.8
2011	25 Sep – 9 Oct	2,146	46	46.7	Weak La Niña	0.2624	20.7
2009	2 April – 21 April	2,854	76	37.6	Normal	0.2850	25.7

Table 11. 4 km^2 spatial bin, Mean Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	0.9798	0.0654	0.1340	0.1095	76	68
April 2009 1 wk before	0	0.9627	0.0741	0.0001	0.9987	66	67
April 2009 2 weeks before	0	0.9998	0.0477	0.0334	0.6887	77	69
April 2009 4 weeks before	0	0.9999	0.0453	0.0359	0.6690	76	68
April 2009 1 week after	0	0.9489	0.0728	0.1350	0.1066	75	69
April 2009 2 weeks after	0	0.9724	0.0687	0.1342	0.1127	73	68
April 2009 4 weeks after	0	0.6045	0.1625	0.3304	0.0028	28	52
Sept/Oct no lag	0	0.8647	0.0929	0.0446	0.4697	47	218
Sept/Oct 1 wk before	0	0.2031	0.1607	-0.0747	0.2365	51	202
Sept/Oct 2 weeks before	0	0.5632	0.1147	0.0433	0.4872	55	205
Sept/Oct 4 weeks before	0	0.1249	0.1667	0.1127	0.0605	58	220
Sept/Oct 1 week after	0	0.4176	0.1201	0.1142	0.0406	62	260
Sept/Oct 2 weeks after	0	0.1789	0.1499	0.1358	0.0164	62	250
Sept/Oct 4 weeks after	1	0.0022	0.2208	0.2327	0.0000	81	335
All cruises no lag	0	0.2173	0.1069	0.1491	0.0025	123	286
All cruises 1 wk before	1	0.0103	0.1690	-0.1035	0.0422	117	269
All cruises 2 weeks before	0	0.7075	0.0695	0.0316	0.5251	132	274
All cruises 4 weeks before	0	0.9363	0.0525	0.0375	0.4428	134	288
All cruises 1 week after	0	0.1801	0.1053	0.1351	0.0035	137	329
All cruises 2 weeks after	0	0.1492	0.1103	0.1847	0.0001	135	318
All cruises 4 weeks after	1	0.0010	0.2032	0.2754	0.0000	109	387

Table 12. 9 km^2 spatial bin, Mean Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	1.0000	0.0387	0.1358	0.1671	76	29
April 2009 1 wk before	0	1.0000	0.0462	0.0002	0.9987	65	26
April 2009 2 weeks before	0	1.0000	0.0356	0.0472	0.6376	76	26
April 2009 4 weeks before	0	1.0000	0.0343	0.0434	0.6666	76	25
April 2009 1 week after	0	0.9998	0.0502	0.0280	0.7790	77	26
April 2009 2 weeks after	0	1.0000	0.0308	0.0362	0.7196	74	27
April 2009 4 weeks after	0	0.8890	0.1310	0.2326	0.1041	29	21
Sept/Oct no lag	0	0.4079	0.1398	0.1033	0.1776	50	122
Sept/Oct 1 wk before	0	0.8276	0.0940	0.0054	0.9409	55	134
Sept/Oct 2 weeks before	0	0.1686	0.1561	0.0991	0.1564	64	142
Sept/Oct 4 weeks before	0	0.1230	0.1627	0.2133	0.0015	66	153
Sept/Oct 1 week after	0	0.2522	0.1346	0.1633	0.0124	72	162
Sept/Oct 2 weeks after	0	0.3034	0.1286	0.1380	0.0360	72	159
Sept/Oct 4 weeks after	1	0.0340	0.1688	0.2331	0.0000	90	211
All cruises no lag	0	0.6538	0.0778	0.1800	0.0026	126	151
All cruises 1 wk before	0	0.3389	0.1012	-0.0685	0.2530	120	160
All cruises 2 weeks before	0	0.9732	0.0487	0.0720	0.2076	140	168
All cruises 4 weeks before	0	0.8410	0.0614	0.1149	0.0401	142	178
All cruises 1 week after	0	0.5801	0.0756	0.1307	0.0164	149	188
All cruises 2 weeks after	0	0.5855	0.0760	0.1644	0.0027	146	186
All cruises 4 weeks after	1	0.0241	0.1555	0.2689	0.0000	119	232

Table 13. 36 km^2 spatial bin, Mean Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	1.0000	0.0496	0.0952	0.4072	61	17
April 2009 1 wk before	0	1.0000	0.0423	-0.0083	0.9413	63	18
April 2009 2 weeks before	0	1.0000	0.0414	0.0928	0.3815	73	18
April 2009 4 weeks before	0	1.0000	0.0402	0.1291	0.2280	71	18
April 2009 1 week after	0	1.0000	0.0377	0.0885	0.4044	74	17
April 2009 2 weeks after	0	0.9998	0.0579	0.1480	0.1961	58	20
April 2009 4 weeks after	0	1.0000	0.0361	-0.0268	0.8841	26	6
Sept/Oct no lag	0	0.9994	0.0568	-0.1175	0.2260	62	46
Sept/Oct 1 wk before	0	0.9580	0.0820	0.0590	0.5520	57	47
Sept/Oct 2 weeks before	0	0.6351	0.1107	0.0240	0.7963	69	49
Sept/Oct 4 weeks before	0	0.5950	0.1244	0.1988	0.0451	57	45
Sept/Oct 1 week after	0	0.9688	0.0644	0.0663	0.4199	90	60
Sept/Oct 2 weeks after	0	0.2112	0.1441	0.2611	0.0016	82	61
Sept/Oct 4 weeks after	0	0.1644	0.1520	0.2906	0.0005	83	57
All cruises no lag	0	1.0000	0.0249	-0.0561	0.4473	123	63
All cruises 1 wk before	0	0.9994	0.0421	-0.0352	0.6345	120	65
All cruises 2 weeks before	0	0.9914	0.0467	0.0413	0.5528	142	67
All cruises 4 weeks before	0	0.8787	0.0663	0.1646	0.0229	128	63
All cruises 1 week after	0	0.9917	0.0434	0.0883	0.1721	164	77
All cruises 2 weeks after	0	0.7100	0.0746	0.2075	0.0019	140	81
All cruises 4 weeks after	0	0.1452	0.1379	0.2774	0.0002	109	63

Table 14. 4 km^2 spatial bin, STD Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	0.4910	0.1166	0.2339	0.0049	75	68
April 2009 1 wk before	0	0.8187	0.0934	0.1357	0.1152	65	71
April 2009 2 weeks before	0	1.0000	0.0370	-0.0197	0.8127	75	72
April 2009 4 weeks before	0	0.9408	0.0738	0.0916	0.2748	76	68
April 2009 1 week after	0	0.3724	0.1284	0.2403	0.0037	74	70
April 2009 2 weeks after	0	0.9975	0.0565	0.0471	0.5818	72	67
April 2009 4 weeks after	0	0.1303	0.2491	0.3938	0.0003	28	51
Sept/Oct no lag	0	0.2780	0.1571	0.0417	0.5097	45	207
Sept/Oct 1 wk before	0	0.6366	0.1122	0.0721	0.2610	51	194
Sept/Oct 2 weeks before	0	0.1870	0.1614	0.1280	0.0440	53	195
Sept/Oct 4 weeks before	0	0.2280	0.1479	0.0977	0.0956	57	235
Sept/Oct 1 week after	1	0.0007	0.2800	0.1940	0.0007	59	240
Sept/Oct 2 weeks after	0	0.4106	0.1230	0.0651	0.2572	60	245
Sept/Oct 4 weeks after	1	0.0375	0.1697	0.1552	0.0023	81	302
All cruises no lag	1	0.0002	0.2241	0.2971	0.0000	120	275
All cruises 1 wk before	1	0.0458	0.1437	0.1488	0.0036	116	265
All cruises 2 weeks before	0	0.1547	0.1135	0.1224	0.0149	128	267
All cruises 4 weeks before	1	0.0031	0.1759	0.2098	0.0000	133	303
All cruises 1 week after	1	0.0000	0.2290	0.3145	0.0000	133	310
All cruises 2 weeks after	0	0.1557	0.1106	0.1705	0.0003	132	312
All cruises 4 weeks after	1	0.0094	0.1719	0.2193	0.0000	109	353

Table 15. 9 km^2 spatial bin, STD Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	0.1437	0.2432	0.1535	0.1198	75	29
April 2009 1 wk before	0	0.5635	0.1769	0.0969	0.3609	65	26
April 2009 2 weeks before	0	0.5809	0.1711	0.0728	0.4670	76	26
April 2009 4 weeks before	0	0.6030	0.1705	0.0524	0.6028	76	25
April 2009 1 week after	0	0.5430	0.1761	0.0719	0.4729	76	26
April 2009 2 weeks after	0	0.7585	0.1462	-0.0043	0.9662	74	27
April 2009 4 weeks after	1	0.0484	0.3699	0.3195	0.0223	29	22
Sept/Oct no lag	1	0.0028	0.3012	0.2028	0.0088	49	117
Sept/Oct 1 wk before	0	0.0781	0.1983	0.1252	0.0853	56	134
Sept/Oct 2 weeks before	0	0.2126	0.1572	0.1077	0.1289	64	136
Sept/Oct 4 weeks before	0	0.0596	0.1940	0.1015	0.1389	64	150
Sept/Oct 1 week after	1	0.0000	0.3712	0.2833	0.0000	70	152
Sept/Oct 2 weeks after	0	0.1726	0.1490	0.1280	0.0437	77	172
Sept/Oct 4 weeks after	1	0.0103	0.2080	0.2169	0.0002	83	202
All cruises no lag	1	0.0000	0.3782	0.3563	0.0000	124	146
All cruises 1 wk before	1	0.0003	0.2507	0.1956	0.0010	121	160
All cruises 2 weeks before	1	0.0326	0.1631	0.1660	0.0038	140	162
All cruises 4 weeks before	1	0.0121	0.1786	0.1928	0.0006	140	175
All cruises 1 week after	1	0.0000	0.3551	0.3309	0.0000	146	178
All cruises 2 weeks after	1	0.0032	0.1910	0.2236	0.0000	151	199
All cruises 4 weeks after	1	0.0002	0.2455	0.2754	0.0000	112	224

Table 16. 36 km^2 spatial bin, STD Chlorophyll

cruise and time lag	Cetacean sighting vs. non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of cetacean locations included in analysis	# of non-sighting locations included in analysis
April 2009 no lag	0	1.0000	0.0434	0.1566	0.1317	77	17
April 2009 1 wk before	0	1.0000	0.0312	0.0314	0.7725	70	17
April 2009 2 weeks before	0	1.0000	0.0287	0.0421	0.6871	77	17
April 2009 4 weeks before	0	1.0000	0.0417	0.0736	0.4811	77	17
April 2009 1 week after	0	1.0000	0.0467	0.0938	0.3684	77	17
April 2009 2 weeks after	0	1.0000	0.0353	-0.0015	0.9883	77	18
April 2009 4 weeks after	0	0.9584	0.1086	0.2936	0.0385	35	15
Sept/Oct no lag	0	0.5691	0.1121	0.1755	0.0459	74	56
Sept/Oct 1 wk before	0	0.2218	0.1635	0.3192	0.0006	61	50
Sept/Oct 2 weeks before	0	0.6580	0.1042	0.2416	0.0064	76	50
Sept/Oct 4 weeks before	0	0.1024	0.1639	0.3352	0.0000	84	62
Sept/Oct 1 week after	0	0.1765	0.1407	0.2833	0.0003	94	66
Sept/Oct 2 weeks after	0	0.1357	0.1501	0.2852	0.0002	88	79
Sept/Oct 4 weeks after	1	0.0222	0.1898	0.3260	0.0000	94	75
All cruises no lag	0	0.3175	0.0995	0.2696	0.0000	151	73
All cruises 1 wk before	0	0.5696	0.0871	0.2288	0.0012	131	67
All cruises 2 weeks before	0	0.8255	0.0652	0.1952	0.0037	153	67
All cruises 4 weeks before	0	0.1941	0.1085	0.3168	0.0000	161	79
All cruises 1 week after	0	0.3202	0.0934	0.2734	0.0000	171	83
All cruises 2 weeks after	0	0.0830	0.1238	0.2810	0.0000	165	97
All cruises 4 weeks after	1	0.0169	0.1690	0.3336	0.0000	129	90

Table 17: Surface and Deep Feeding Cetacean Statistics for Sightings vs. Mean and Standard Deviation of Chlorophyll

cruise and time lag	Surface Feeders vs. Non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of surface feeder locations included in analysis	Deep Feeders vs. Non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of deep feeder locations included in analysis	# of non-sighting locations included in analysis
4 km 4 Day Composited Mean Chlorophyll													
All cruises no lag	1	0.0109	0.3462	0.1473	0.0092	22	1	0.0121	0.3182	0.1290	0.0235	26	286
All cruises 1 wk before	0	0.3552	0.1884	-0.0018	0.9755	25	0	0.7484	0.1592	-0.0500	0.3935	18	269
All cruises 2 weeks before	0	0.5886	0.1541	0.1207	0.0376	26	0	0.0506	0.2855	0.0061	0.9168	23	274
All cruises 4 weeks before	1	0.0177	0.3058	-0.0226	0.6887	26	0	0.9363	0.1032	0.1364	0.0156	28	288
All cruises 1 week after	1	0.0020	0.3678	0.0600	0.2567	26	0	0.5544	0.1474	0.1079	0.0421	30	329
All cruises 2 weeks after	0	0.0970	0.2438	0.0911	0.0915	26	0	0.0952	0.2446	0.0784	0.1466	26	318
All cruises 4 weeks after	1	0.0000	0.4965	0.0857	0.0827	26	0	0.0833	0.2574	0.2321	0.0000	24	387
9 km 4 Day Composited Mean Chlorophyll													
All cruises no lag	1	0.0024	0.3907	0.1974	0.0089	24	1	0.0029	0.3672	0.2436	0.0011	27	151
All cruises 1 wk before	0	0.7095	0.1463	-0.0363	0.6237	25	0	0.6467	0.1771	0.0632	0.4017	18	160
All cruises 2 weeks before	0	0.1698	0.2202	0.0181	0.8015	28	0	0.1500	0.2367	0.1284	0.0752	25	168
All cruises 4 weeks before	1	0.0268	0.2901	0.1980	0.0043	28	0	0.6118	0.1478	-0.0096	0.8910	29	178
All cruises 1 week after	1	0.0038	0.3432	0.1420	0.0366	29	0	0.5138	0.1506	0.1137	0.0919	33	188
All cruises 2 weeks after	0	0.0926	0.2406	0.0961	0.1604	29	0	0.1982	0.2151	0.0980	0.1543	27	186
All cruises 4 weeks after	1	0.0002	0.4095	0.2637	0.0000	29	0	0.3874	0.1707	0.0642	0.3006	30	232
36 km 4 Day Composited Mean Chlorophyll													
All cruises no lag	0	0.1957	0.2430	0.0018	0.9861	26	0	0.5510	0.1730	-0.0076	0.9439	29	63
All cruises 1 wk before	0	0.1704	0.2429	0.0450	0.6825	28	0	0.8072	0.1577	0.0274	0.7944	20	65
All cruises 2 weeks before	1	0.0315	0.3140	0.1042	0.3204	28	0	0.2824	0.2210	-0.0093	0.9289	26	67
All cruises 4 weeks before	1	0.0030	0.3968	0.0524	0.6379	28	0	0.9271	0.1349	0.2467	0.0184	20	63
All cruises 1 week after	0	0.0603	0.2732	0.0341	0.7184	31	0	0.4175	0.1716	0.0960	0.3230	37	77
All cruises 2 weeks after	1	0.0008	0.4066	0.2024	0.0357	31	0	0.0830	0.2716	0.2724	0.0037	27	81
All cruises 4 weeks after	1	0.0023	0.3907	0.0899	0.4048	31	0	0.1568	0.2578	0.3334	0.0010	25	63
4 km 4 Day Composited STD Chlorophyll													
All cruises no lag	1	0.0015	0.4073	0.1172	0.0425	22	0	0.0857	0.2546	0.2199	0.0001	25	275
All cruises 1 wk before	0	0.4364	0.1766	0.1306	0.0281	25	1	0.0286	0.3428	0.0430	0.4661	18	265
All cruises 2 weeks before	0	0.8733	0.1205	0.0966	0.1012	25	0	0.0841	0.2705	0.0113	0.8473	22	267
All cruises 4 weeks before	1	0.0226	0.3026	0.0374	0.4969	25	0	0.6584	0.1384	0.1578	0.0042	29	303
All cruises 1 week after	1	0.0000	0.5761	0.0805	0.1397	25	0	0.3297	0.1820	0.3176	0.0000	28	310
All cruises 2 weeks after	0	0.3521	0.1878	0.1878	0.0314	25	0	0.8452	0.1218	0.0734	0.1789	26	312
All cruises 4 weeks after	1	0.0133	0.3182	0.3182	0.0604	25	0	0.2960	0.2000	0.1936	0.0002	24	353
9 km 4 Day Composited STD Chlorophyll													
All cruises no lag	1	0.0000	0.5474	0.2346	0.0020	24	1	0.0173	0.3236	0.3317	0.0000	25	146
All cruises 1 wk before	1	0.0162	0.3238	0.1323	0.0784	25	0	0.0541	0.3222	0.1634	0.0262	18	160
All cruises 2 weeks before	0	0.7467	0.1349	0.1127	0.1245	28	0	0.1728	0.2306	-0.0217	0.7659	25	162
All cruises 4 weeks before	0	0.3791	0.1800	0.0227	0.7472	28	0	0.9058	0.1103	0.1092	0.1209	29	175
All cruises 1 week after	1	0.0000	0.4976	0.1603	0.0204	28	1	0.0096	0.3094	0.3522	0.0000	31	178
All cruises 2 weeks after	1	0.0322	0.2778	0.1597	0.0163	29	0	0.0531	0.2684	0.1236	0.0625	27	199
All cruises 4 weeks after	1	0.0003	0.4056	0.0484	0.4434	29	0	0.6641	0.1398	0.3136	0.0000	29	224
36 km 4 Day Composited STD Chlorophyll													
All cruises no lag	1	0.0010	0.4207	0.2669	0.0059	28	1	0.0049	0.3570	0.2177	0.0287	32	73
All cruises 1 wk before	1	0.0004	0.4510	0.2110	0.0498	28	0	0.0869	0.3075	0.3392	0.0008	20	67
All cruises 2 weeks before	1	0.0068	0.3673	0.0873	0.3927	28	0	0.5628	0.1661	0.2126	0.0386	31	67
All cruises 4 weeks before	1	0.0001	0.4768	0.1926	0.0438	30	1	0.0211	0.3103	0.3282	0.0005	31	79
All cruises 1 week after	1	0.0000	0.4808	0.2226	0.0146	31	0	0.1992	0.2065	0.3158	0.0006	37	83
All cruises 2 weeks after	1	0.0003	0.4187	0.1861	0.0326	31	1	0.0212	0.2893	0.3221	0.0002	35	97
All cruises 4 weeks after	1	0.0000	0.5240	0.1763	0.0530	31	1	0.0026	0.3685	0.5099	0.0000	31	90

Table 18: Surface and Deep Feeding Cetacean Statistics for Sightings vs. Mean and Standard Deviation of SST

cruise	Surface Feeders vs. Non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of surface feeder locations included in analysis	Deep Feeders vs. Non-sighting K-S test h value	p-value	k statistic	correlation coefficient	p-value	# of surface feeder locations included in analysis
April 2009 Mean SST	0	0.1129	0.51471	0.15272	0.19708	5	0	0.43367	0.23824	0.0068	0.95132	15
September/October 2008-2011	1	0.04701	0.27908	-0.1293	0.00655	24	0	0.56942	0.17796	0.02362	0.62284	19
All cruises	0	0.09986	0.22787	-0.06062	0.16995	29	1	0.03644	0.245	0.13959	0.00143	34
April 2009 Mean SST	0	0.1129	0.51471	0.14911	0.208	5	0	0.43367	0.23824	0.00164	0.98824	15
September/October 2008-2011	0	0.09464	0.2378	-0.10903	0.01544	27	0	0.84307	0.13605	-0.01339	0.76837	20
All cruises	0	0.15757	0.20002	-0.05149	0.22128	32	1	0.03854	0.24256	0.12958	0.00197	34
April 2009 Mean SST	1	0.01396	0.67647	0.20193	0.08667	5	0	0.47123	0.23137	0.02424	0.82779	15
September/October 2008-2011	1	0.01368	0.28742	-0.11519	0.00291	30	0	0.52637	0.1783	-0.02938	0.45256	20
All cruises	0	0.07905	0.21494	-0.05818	0.11402	35	0	0.08661	0.21474	0.10781	0.00337	34
April 2009 STD SST	0	0.73599	0.29412	-0.03744	0.75314	5	1	0.02546	0.40392	-0.27705	0.01123	15
September/October 2008-2011	1	0.00106	0.39604	0.29727	0	24	0	0.22095	0.23814	0.0192	0.69382	19
All cruises	1	0.00033	0.38844	0.24273	0	29	0	0.06796	0.22532	0.01681	0.70598	34
April 2009 STD SST	0	0.20954	0.45588	0.04444	0.70892	5	0	0.05593	0.36569	-0.27079	0.01328	15
September/October 2008-2011	1	0.03064	0.27856	0.18896	0.00003	27	0	0.45303	0.1898	0.02434	0.5982	20
All cruises	0	0.06129	0.23447	0.16674	0.00008	32	1	0.01918	0.26335	0.03843	0.367	34
April 2009 STD SST	0	0.14592	0.49118	0.15613	0.18716	5	1	0.02192	0.41078	-0.29897	0.00604	15
September/October 2008-2011	1	0.01653	0.28207	0.15851	0.00005	30	0	0.07344	0.28271	0.03841	0.33236	20
All cruises	1	0.00154	0.32032	0.15913	0.00002	35	1	0.02425	0.25473	0.03421	0.35897	34

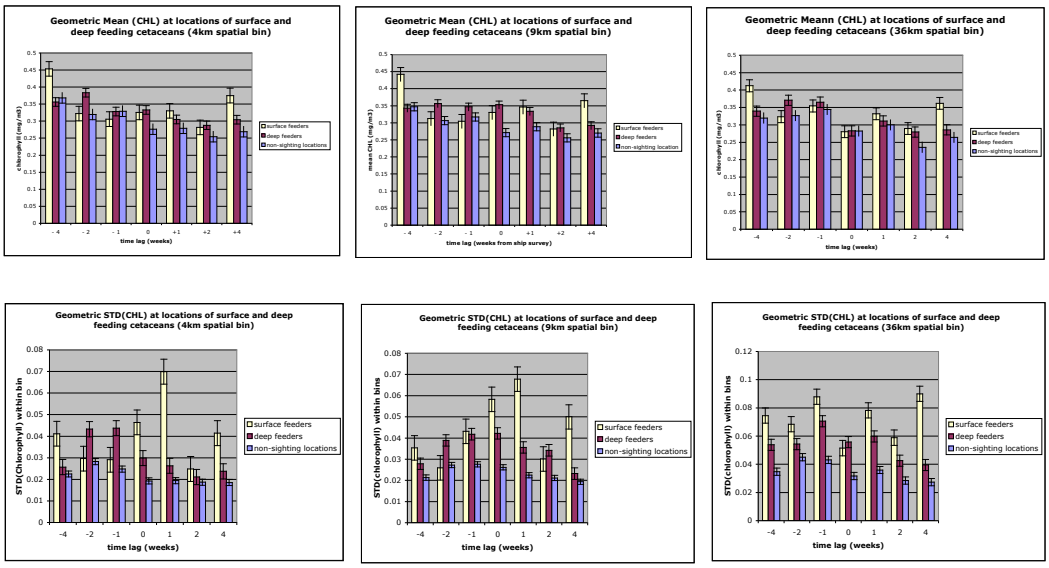


Figure 11. Mean and STD Chlorophyll at locations of surface feeding, deep-feeding cetaceans and non-sightings. Data is from monthly MODIS composites.

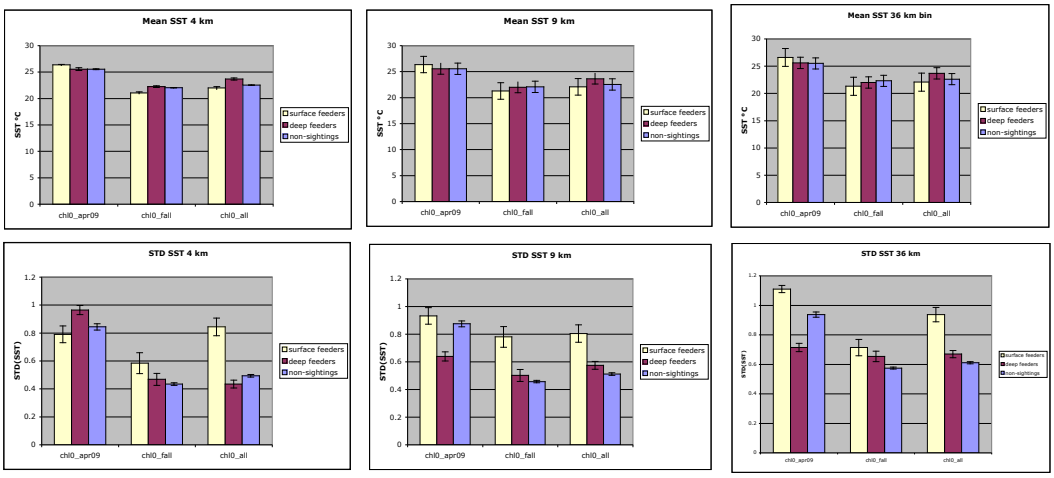
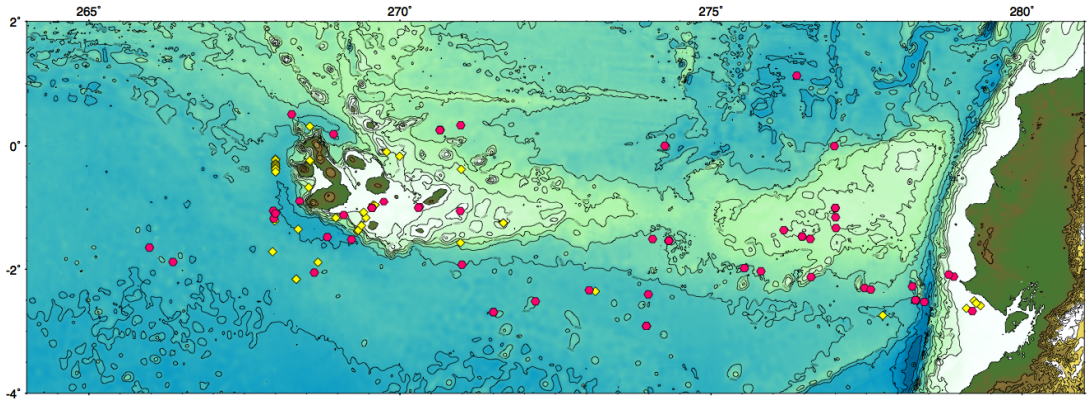


Figure 12. Mean and STD of SST at locations of surface feeding and deep feeding cetaceans and non-sightings. Data is from monthly MODIS composites.



yellow dots: surface-feeders
pink dots: deep-divers

Figure 13: Sightings of surface-feeding cetaceans vs. deep-feeding cetaceans, Cruises aboard the *B/I Orion*, 2008-2011

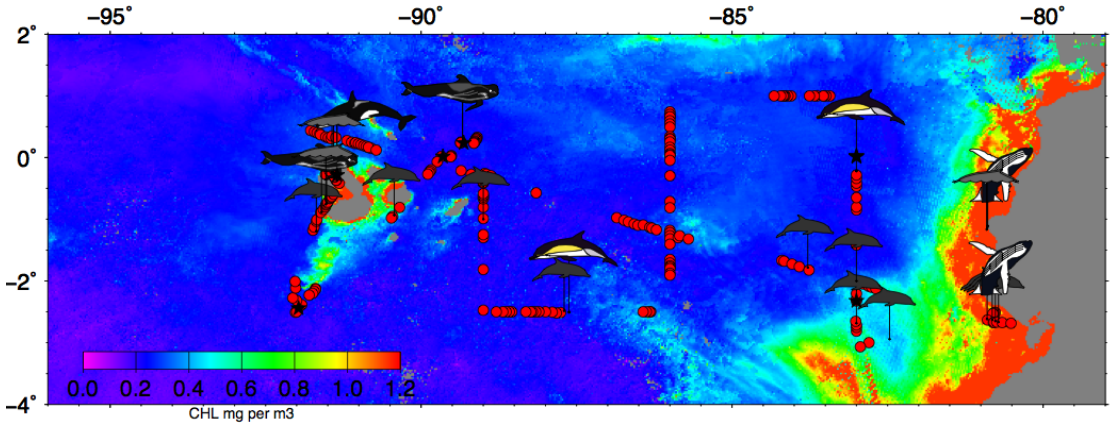


Figure 14. Cetacean sightings overlaid on MODIS ocean color monthly composite for time of survey. September 2008.

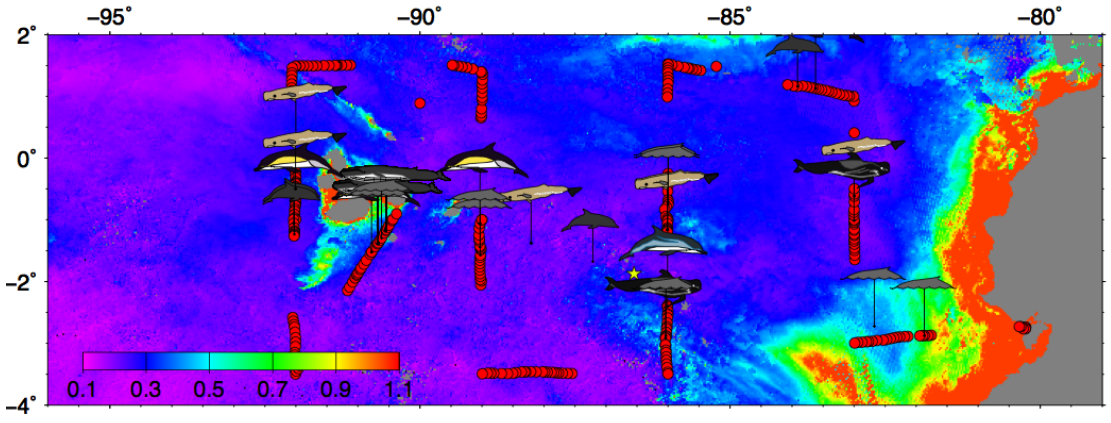


Figure 15. Cetacean sightings overlaid on MODIS ocean color, monthly composite for time of survey. Red dots indicate survey effort. September 2009.

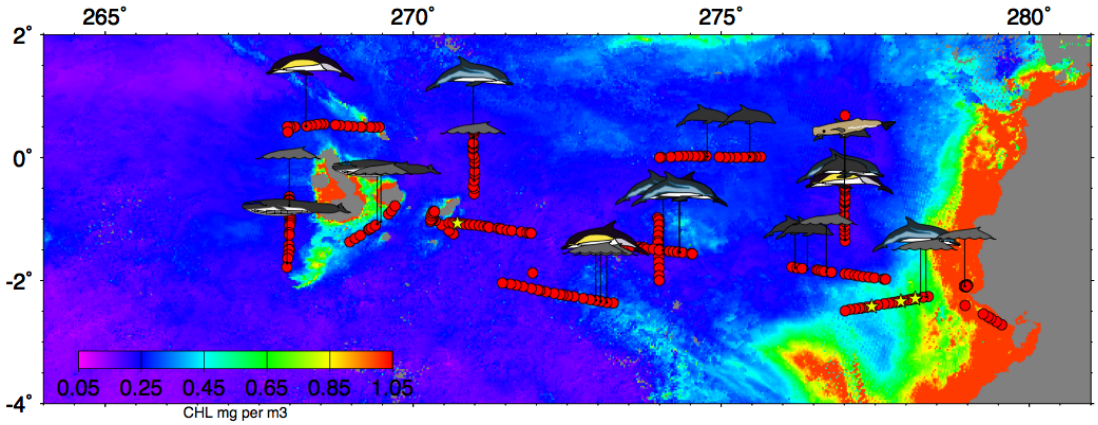


Figure 16. Cetacean sightings overlaid on MODIS ocean color, monthly composite for time of survey. September 2010.

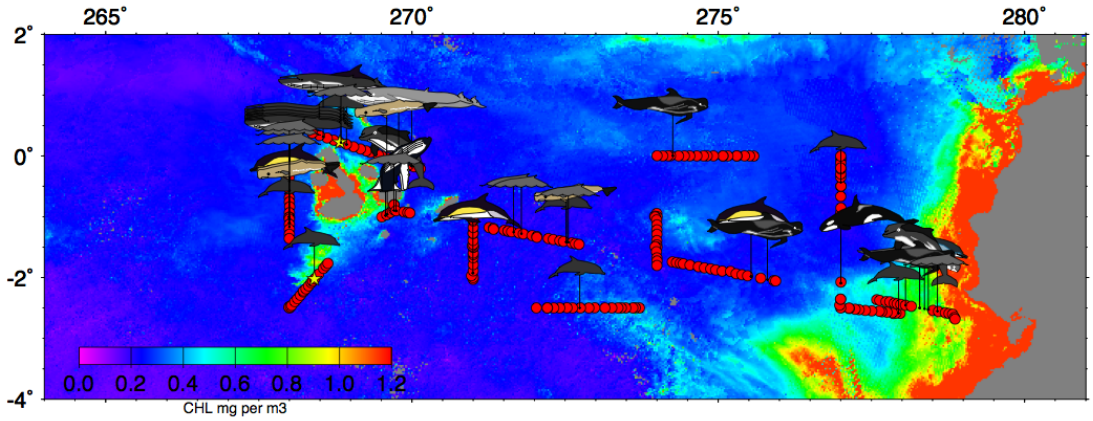


Figure 17. Cetacean sightings overlaid on MODIS ocean color, monthly composite for time of survey. September 2011.

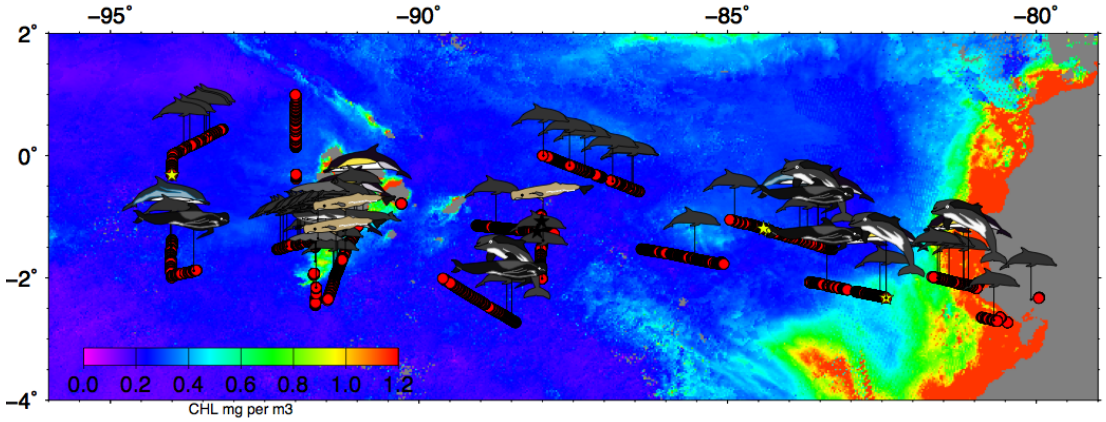


Figure 18. Cetacean sightings overlaid on MODIS ocean color, monthly composite for time of survey. April 2009.

APPENDIX C

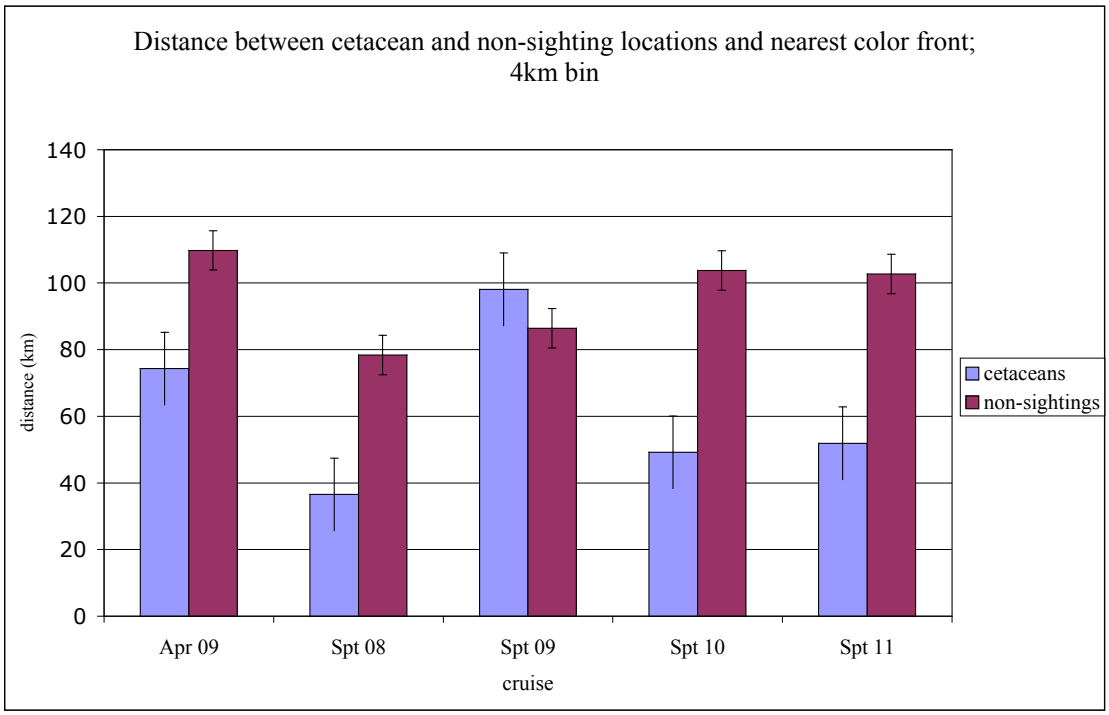


Figure 19. Mean distance between cetacean sighting and color front, 4 km^2 spatial bin of MODIS data.

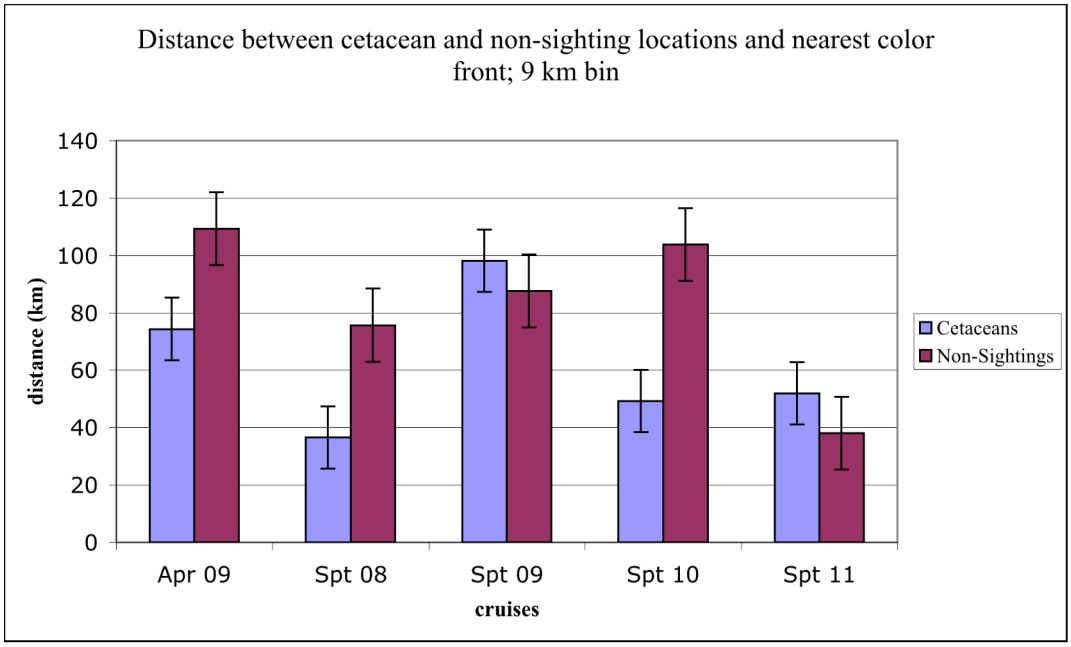


Figure 20. Mean distance between cetacean sighting and color front, 9 km^2 spatial bin of MODIS data.

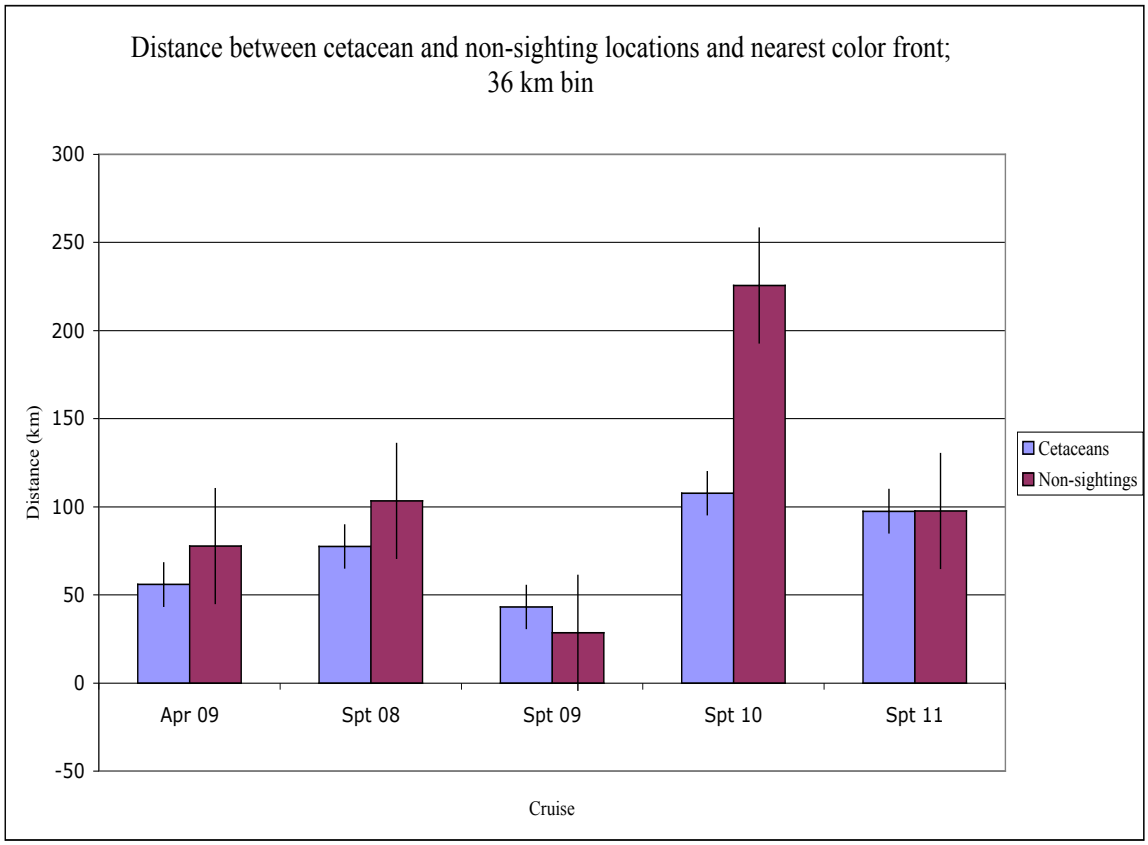


Figure 21. Mean distance between cetacean sighting and color front, 36 km^2 spatial bin of MODIS data.

Table 18: Correlations between cetacean presence/absence and ocean color fronts

Sighting Groups	4km Pearson correlation coefficient	p-value	9km Pearson correlation coefficient	p-value	36km Pearson correlation coefficient	p-value
All cetaceans	-0.1536	<.0001	-0.1694	<.0001	-0.1111	0.0348
Surface-feeding cetaceans	-0.1676	<.0001	-0.2233	<.0001	-0.3259	0
Deep-feeding cetaceans	-0.0605	0.057	-0.0713	0.099	-0.029	0.7

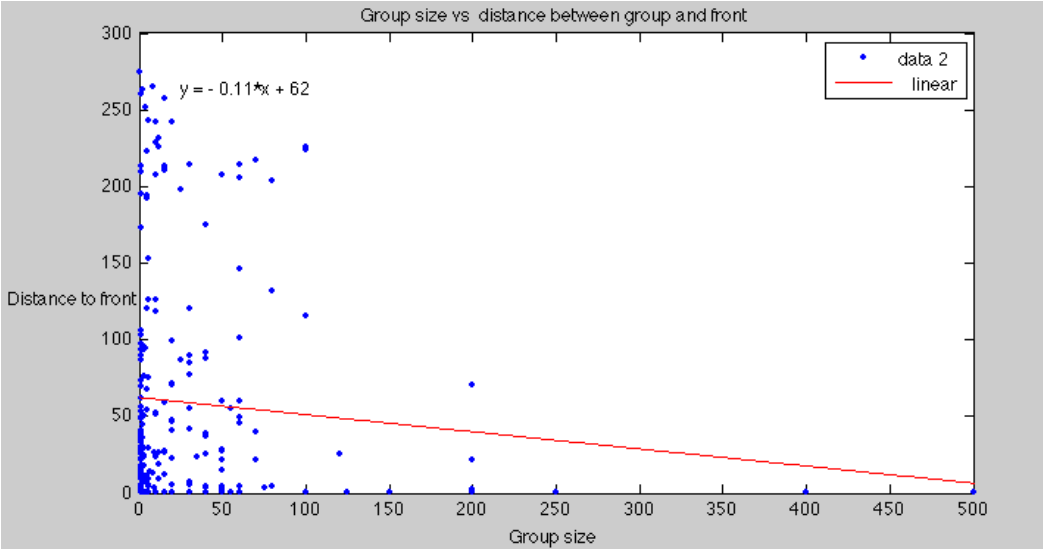


Figure 22. Cetacean sighting distance to the nearest color front as a function of group size; Color data are binned at 4 km^2.

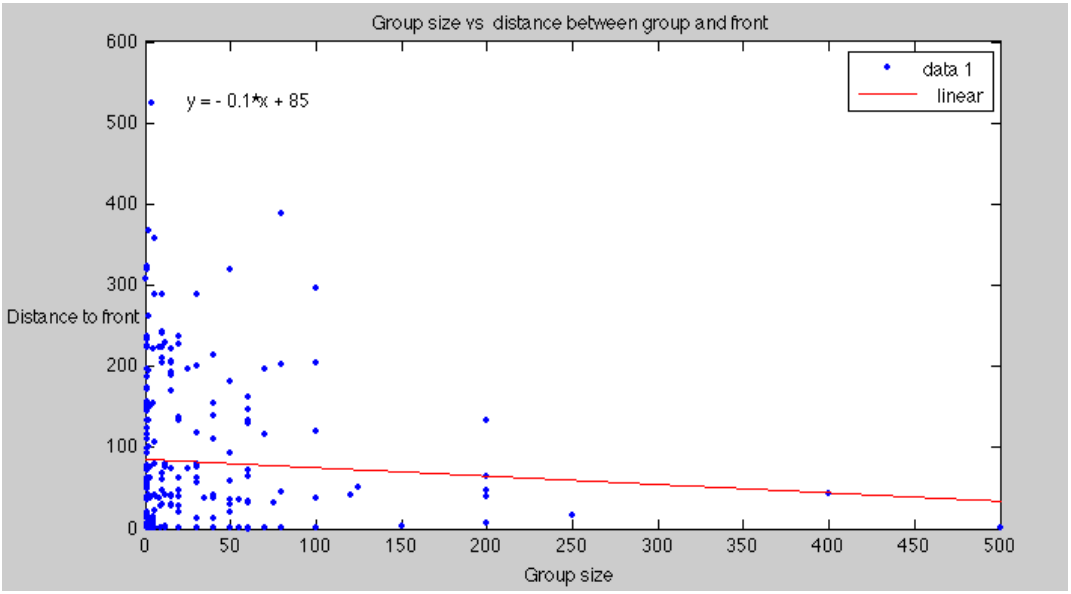


Figure 23. Cetacean sighting distance to the nearest color front as a function of group size; Color data are binned at 9 km^2.

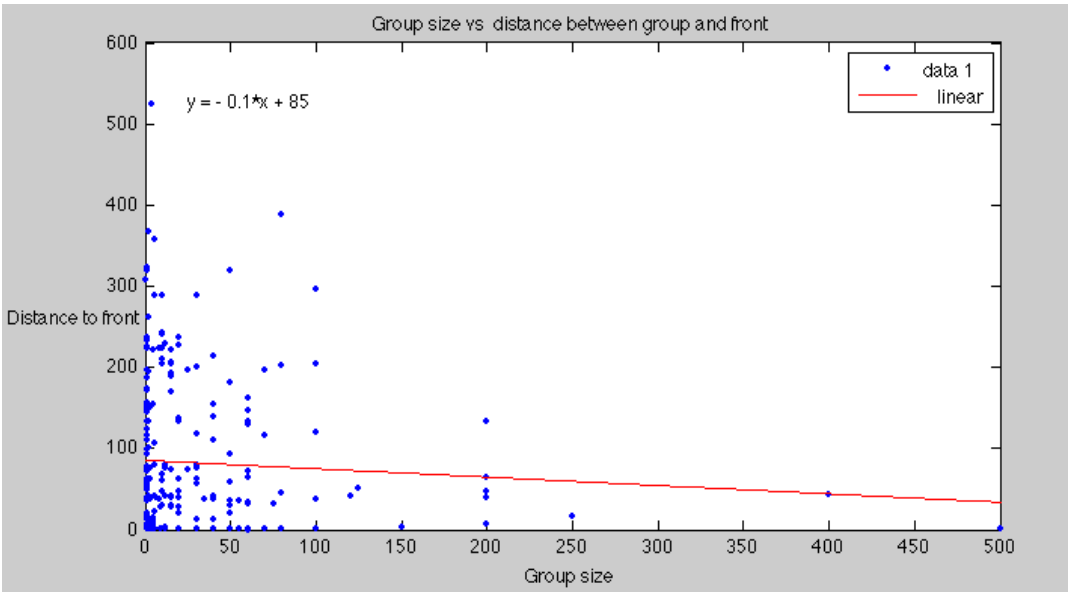


Figure 24. Cetacean sighting distance to the nearest color front as a function of group size; Color data are binned at 36 km^2.

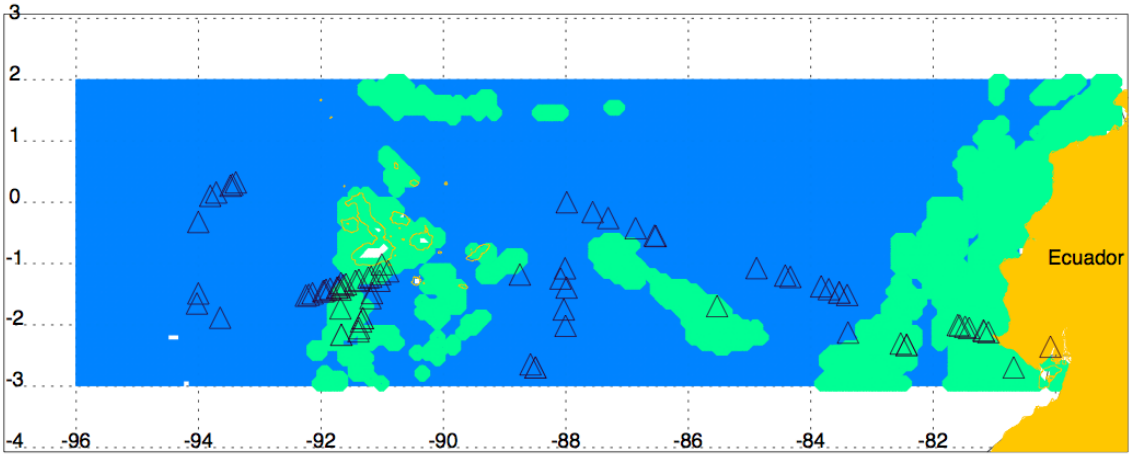


Figure 25. April 2009 cetacean sightings overlaid on MODIS binned ocean color fronts. MODIS ocean color is composited over 1 month and binned at 9 km^2; blue dots represent locations where quality-controlled ocean color data were available. Green dots indicate bins where the standard deviation within the bin is identified as a potential color front. Triangles are locations of cetacean sightings.

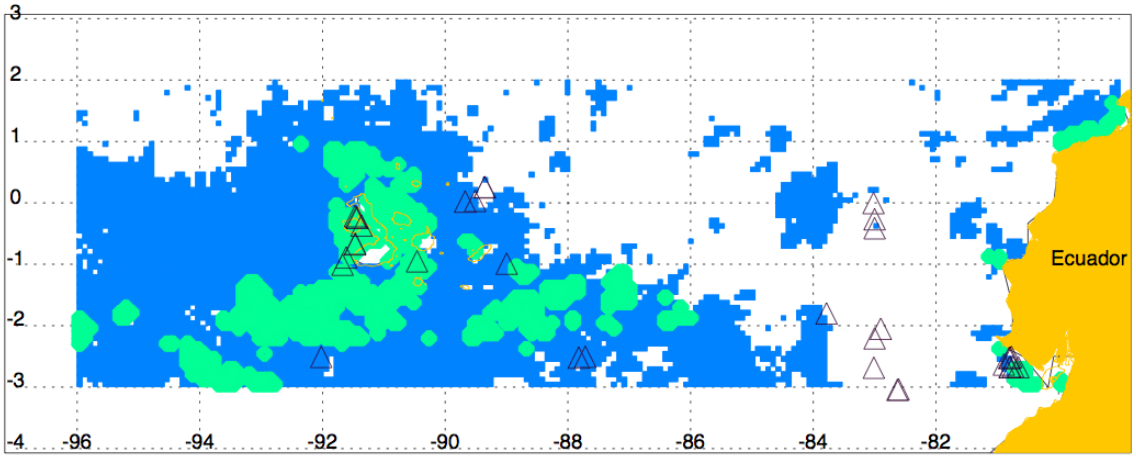


Figure 26. September 2008 cetacean sightings overlaid on MODIS binned ocean color fronts. MODIS ocean color is composited over 1 month and binned at 9 km^2; blue dots represent locations where quality-controlled ocean color data were available. Green dots indicate bins where the standard deviation within the bin is identified as a potential color front. Triangles are locations of cetacean sightings.

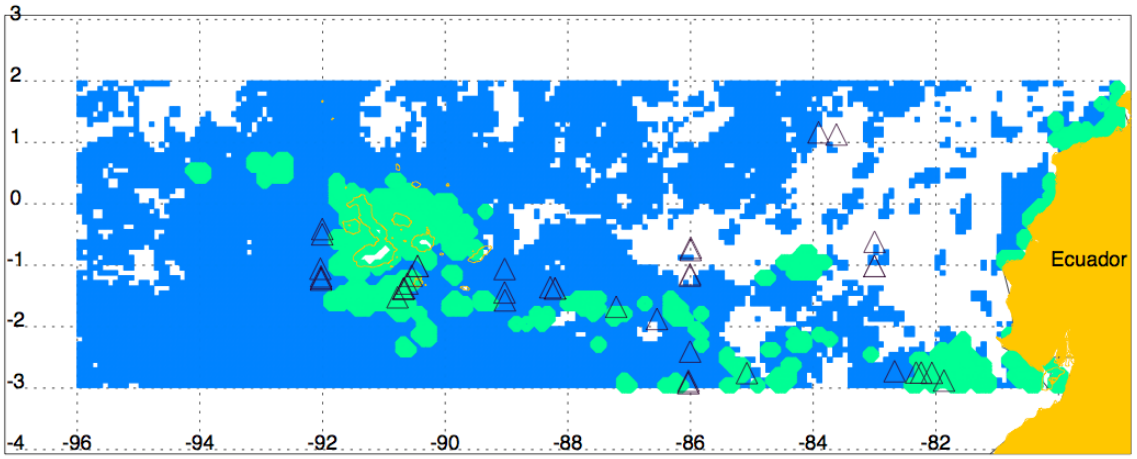


Figure 27. September 2009 cetacean sightings overlaid on MODIS binned ocean color fronts. MODIS ocean color is composited over 1 month and binned at 9 km^2; blue dots represent locations where quality-controlled ocean color data were available. Green dots indicate bins where the standard deviation within the bin is identified as a potential color front. Triangles are locations of cetacean sightings.

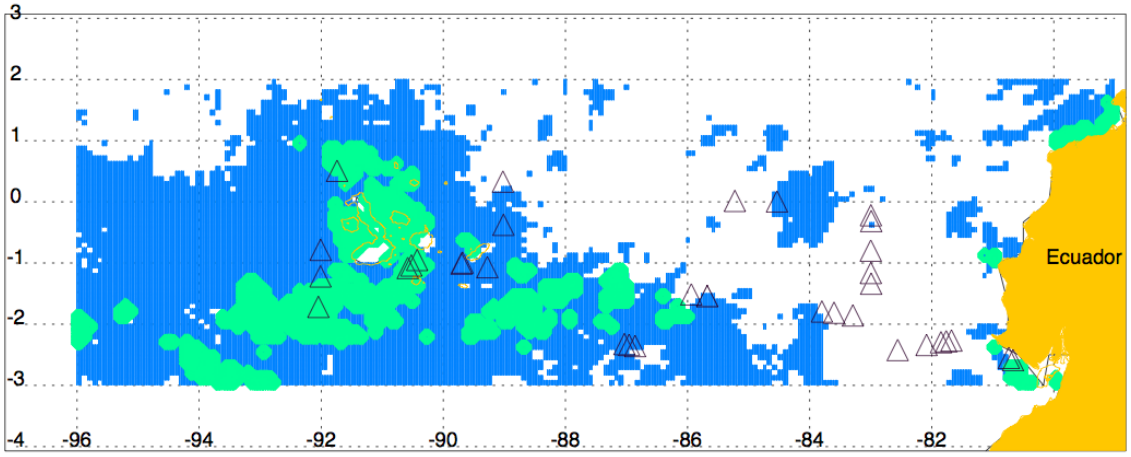


Figure 28. September 2010 cetacean sightings overlaid on MODIS binned ocean color fronts. MODIS ocean color is composited over 1 month and binned at 9 km^2; blue dots represent locations where quality-controlled ocean color data were available. Green dots indicate bins where the standard deviation within the bin is identified as a potential color front. Triangles are locations of cetacean sightings.

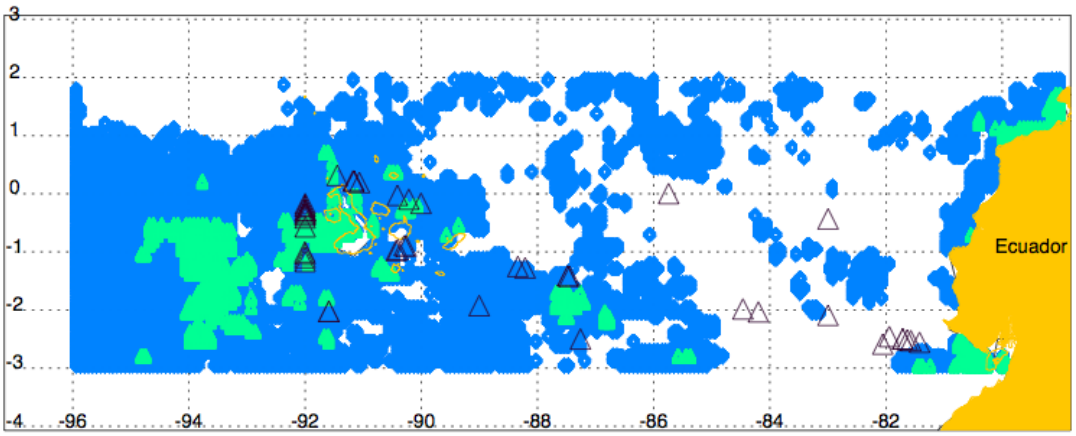


Figure 29. September 2011 cetacean sightings overlaid on MODIS binned ocean color fronts. MODIS ocean color is composited over 1 month and binned at 9 km^2; blue dots represent locations where quality-controlled ocean color data were available. Green dots indicate bins where the standard deviation within the bin is identified as a potential color front. Triangles are locations of cetacean sightings.

APPENDIX D

Table 19. Summary of all sightings used for analysis in this dissertation. Survey program is listed in the last column. All 'common dolphins' are *Delphinus delphis* and all 'pilot whales' are *Globicephala macrohynchus*. All positions are decimal degrees.

Year	Day of Year	Longitude	Latitude	Cetacean	Group Size	Program
2001	260.56	-79.9102	-2.2653	bottlenose dolphin	3	INOCAR
2001	260.65	-80.0298	-2.4247	bottlenose dolphin	1	INOCAR
2001	260.75	-80.0222	-2.6137	bottlenose dolphin	2	INOCAR
2001	261.63	-81.0802	-2.141	common dolphin	50	INOCAR
2001	261.74	-81.1558	-1.9992	humpback whale	3	INOCAR
2001	261.43	-81.1333	-2.6333	unid dolphin	2	INOCAR
2001	261.59	-81.1333	-2.2333	unid dolphin	9	INOCAR
2001	262.71	-81.0783	-0.5782	blue whale	1	INOCAR
2001	262.3	-80.8128	-0.9168	humpback whale	1	INOCAR
2001	262.42	-80.7188	-0.9253	humpback whale	2	INOCAR
2001	264.51	-84.169	1.0348	pilot whale	12	INOCAR
2001	264.57	-84.3275	1.0495	pilot whale	1	INOCAR
2001	264.51	-84.1667	0.9667	unid dolphin	4	INOCAR
2001	264.53	-84.3167	0.9667	unid odontocete	2	INOCAR
2001	264.75	-84.7833	-0.9667	unid dolphin	5	INOCAR
2001	265.56	-85.0177	0.577	Pantropical spotted dolphin	20	INOCAR
2001	265.58	-85.0192	0.5635	pilot whale	25	INOCAR
2001	265.58	-85.0167	0.55	Pantropical spotted dolphin	5	INOCAR
2001	267.56	-85.012	-3.4868	orca	6	INOCAR
2001	267.71	-85.35	-2.7833	unid odontocete	2	INOCAR
2001	269.78	-89	-2.7833	unid dolphin	1	INOCAR
2001	270.38	-89.0187	-0.0563	pilot whale	90	INOCAR
2001	270.38	-89.0167	-0.5	common dolphin	5	INOCAR
2001	270.38	-89.0167	-0.5	bottlenose dolphin	5	INOCAR
2001	271.61	-89.6165	-0.8928	bottlenose dolphin	17	INOCAR
2001	278.53	-90.1055	-0.5268	striped Dolphin	90	INOCAR
2001	278.57	-90.65	-0.65	bottlenose dolphin	60	INOCAR
2001	280.61	-84.7358	-1.905	pilot whale	20	INOCAR
2001	280.3	-85.5833	-1.9	unid dolphin	50	INOCAR
2001	281.66	-81.7833	-2.4667	unid dolphin	4	INOCAR
2008	267.74	-80.8459	3.0354	humpback whale	3	INOCAR
2008	267.75	-80.8477	-3.0028	unid small whale	1	INOCAR
2008	267.75	-80.8492	-2.9803	unid small whale	1	INOCAR
2008	268.29	-82.4667	-2.9412	unid dolphin	5	INOCAR
2008	268.3	-82.4667	-2.9467	unid small whale	1	INOCAR
2008	268.61	-83	-2.6833	unid dolphin	12	INOCAR
2008	268.75	-83	-2.3233	unid small whale	5	INOCAR
2008	269.6	-83	0.0264	unid small whale	1	INOCAR
2008	269.64	-83	0.0132	unid small whale	1	INOCAR
2008	269.72	-83	-0.2132	common dolphin	100	INOCAR
2008	273.36	-87.7	-2.4833	unid dolphin	50	INOCAR
2008	273.39	-87.6211	-2.5042	common dolphin	15	INOCAR
2008	274.39	-89	-1	unid dolphin	8	INOCAR
2008	275.43	-89.3333	-0.2333	pilot whale	1	INOCAR
2008	275.44	-89.3333	-0.2333	pilot whale	2	INOCAR
2008	275.6	-89.3134	-0.2294	unid small whale	1	INOCAR
2008	275.62	-89.65	-0.0167	unid small whale	5	INOCAR
2008	278.73	-90.4333	-0.9333	unid small whale	30	INOCAR
2008	279.4	-91.9704	-2.4422	unid large whale	1	INOCAR
2008	280.3	-91.6846	-1.1894	unid dolphin	12	INOCAR
2008	280.35	-91.6	-0.8833	pilot whale	20	INOCAR
2008	280.45	-91.5304	-0.7548	unid large whale	1	INOCAR
2008	280.46	-91.5192	-0.7372	blue whale	1	INOCAR
2008	280.68	-91.35	0.3667	orca	4	INOCAR
2008	280.75	-91.4333	-0.2333	blue whale	1	INOCAR
2008	280.75	-91.4087	-0.2481	blue whale	1	INOCAR
2008	280.76	-91.3502	-0.2833	unid small whale	3	INOCAR
2008	284.37	-83.7833	-1.7833	unid dolphin	20	INOCAR
2008	284.62	-83	-2	unid dolphin	60	INOCAR
2008	285.24	-80.9	-2.6167	humpback whale	1	INOCAR
2008	285.27	-80.8167	-2.6333	Pantropical spotted dolphin	6	INOCAR
2008	285.29	-80.8186	-2.6315	unid dolphin	6	INOCAR
2008	285.29	-80.7667	-2.65	unid dolphin	55	INOCAR
2008	285.3	-80.7167	-2.6667	unid dolphin	30	INOCAR
2009	280.57	-80.2	-2.5	bottlenose dolphin	3	INOCAR
2009	281.32	-81.8679	-2.8776	unid large whale	1	INOCAR
2009	282.49	-83.0014	-1.0117	bottlenose dolphin	25	INOCAR
2009	282.68	-82.9992	-0.6173	sperm whale	3	INOCAR
2009	283.58	-83.6211	1.1292	common dolphin	30	INOCAR
2009	283.7	-83.9131	1.1626	unid dolphin	15	INOCAR
2009	285.46	-85.9978	-0.7151	unid large whale	1	INOCAR
2009	285.48	-85.9995	-0.7525	unid large whale	1	INOCAR
2009	285.73	-86.0087	-1.1481	sperm whale	3	INOCAR
2009	285.74	-86.0091	-1.1681	sperm whale	1	INOCAR
2009	286.28	-86.0081	-2.4063	striped Dolphin	12	INOCAR
2009	286.46	-86.0347	-2.8821	unid large whale	1	INOCAR
2009	286.47	-86.039	-2.9175	pilot whale	12	INOCAR
2009	286.48	-86.039	-2.9175	bottlenose dolphin	6	INOCAR
2009	288.44	-89.0266	-1.5725	blue whale	1	INOCAR
2009	288.49	-89.0323	-1.4438	unid large whale	1	INOCAR
2009	288.61	-89.0312	-1.0614	common dolphin	55	INOCAR
2009	291.34	-92.004	-0.4111	sperm whale	3	INOCAR
2009	291.36	-92.0048	-0.4965	sperm whale	1	INOCAR
2009	291.64	-92.0358	-1.0573	common dolphin	120	INOCAR
2009	291.68	-92.0255	-1.1828	common dolphin	12	INOCAR
2009	291.74	-92.0234	-1.2113	unid large whale	2	INOCAR
2009	291.75	-92.0254	-1.2341	unid dolphin	6	INOCAR
2009	293.52	-90.7789	-1.5229	common dolphin	200	INOCAR

Year	Day of Year	Longitude	Latitude	Cetacean	Group Size	Program
2009	293.57	-90.6842	-1.3874	blue whale	1	INOCAR
2009	293.57	-90.6724	-1.3728	blue whale	1	INOCAR
2009	293.6	-90.6186	-1.2973	blue whale	1	INOCAR
2009	293.64	-90.5476	-1.17	blue whale	1	INOCAR
2009	293.7	-90.4507	-1.0115	bottlenose dolphin	7	INOCAR
2009	298.72	-88.2875	-1.3594	unid large whale	1	INOCAR
2009	298.74	-88.2093	-1.3785	unid beaked whale	1	INOCAR
2009	298.74	-88.2093	-1.3785	sperm whale	2	INOCAR
2009	299.3	-87.2117	-1.6776	unid dolphin	5	INOCAR
2009	299.55	-86.548	-1.8749	unid odontocete	1	INOCAR
2009	301.41	-85.0823	-2.7564	unid dolphin	50	INOCAR
2009	302.48	-82.673	-2.7258	unid large whale	1	INOCAR
2009	302.65	-82.3227	-2.7457	unid dolphin	30	INOCAR
2009	302.68	-82.2384	-2.7453	humpback whale	1	INOCAR
2009	302.74	-82.0652	-2.7522	unid dolphin	80	INOCAR
2009	293.57	-90.6724	-1.3728	blue whale	1	INOCAR
2009	282.49	-83.0014	-1.0117	bottlenose dolphin	25	INOCAR
2009	293.7	-90.4507	-1.0115	bottlenose dolphin	7	INOCAR
2010	266.74	-80.6687	-2.5876	humpback whale	2	INOCAR
2010	266.76	-80.737	-2.5495	humpback whale	1	INOCAR
2010	268.28	-81.6771	-2.2674	unid large whale	3	INOCAR
2010	268.31	-81.7636	-2.28	striped Dolphin	30	INOCAR
2010	268.34	-81.8488	-2.2958	unid odontocete	4	INOCAR
2010	268.42	-82.0852	-2.3399	unid odontocete	5	INOCAR
2010	268.58	-82.5576	-2.4224	unid odontocete	1	INOCAR
2010	269.28	-82.9919	-1.3373	common dolphin	15	INOCAR
2010	269.33	-82.998	-1.1633	striped Dolphin	50	INOCAR
2010	269.51	-82.9982	-0.7972	unid dolphin	60	INOCAR
2010	269.69	-82.9914	-0.3137	sperm whale	1	INOCAR
2010	269.72	-82.997	-0.219	unid dolphin	70	INOCAR
2010	270.33	-84.5348	0.0075	unid dolphin	15	INOCAR
2010	270.53	-85.2255	0.0155	unid dolphin	15	INOCAR
2010	272.33	-86.8594	-2.3571	blue whale	1	INOCAR
2010	272.36	-86.9587	-2.3394	common dolphin	70	INOCAR
2010	272.38	-87.0345	-2.3248	unid large whale	1	INOCAR
2010	273.4	-89.6855	-0.992	bottlenose dolphin	35	INOCAR
2010	273.42	-89.7031	-1.0088	bottlenose dolphin	15	INOCAR
2010	275.42	-89.0152	-0.3755	blue whale	1	INOCAR
2010	275.75	-89.0237	0.3317	striped Dolphin	30	INOCAR
2010	276.6	-91.741	0.5086	common dolphin	50	INOCAR
2010	277.35	-92.01	-0.7839	unid large whale	1	INOCAR
2010	277.56	-92.0129	-1.2195	sei-Brydes whale	1	INOCAR
2010	277.77	-92.0476	-1.7174	blue whale	1	INOCAR
2010	278.52	-90.5837	-1.0813	blue whale	1	INOCAR
2010	278.55	-90.5231	-1.0403	unid large whale	1	INOCAR
2010	278.58	-90.4302	-0.9498	humpback whale	1	INOCAR
2010	280.35	-89.2796	-1.068	unid odontocete	1	INOCAR
2010	281.6	-85.9386	-1.5129	striped Dolphin	50	INOCAR
2010	281.69	-85.678	-1.5402	common dolphin	20	INOCAR
2010	282.29	-83.7997	-1.7926	unid dolphin	6	INOCAR
2010	282.35	-83.601	-1.8132	unid dolphin	8	INOCAR
2010	282.46	-83.2924	-1.8568	unid large whale	1	INOCAR
2010	281.69	-85.678	-1.5402	striped Dolphin	20	INOCAR
2011	250.2951	-82.0559	-2.5882	unid dolphin	30	INOCAR
2011	250.7688	-82.9988	-2.0929	killer whale	1	INOCAR
2011	251.0764	-82.9981	-0.4336	unid dolphin	0	INOCAR
2011	252.1799	-85.7429	0.0029	pilot whale	4	INOCAR
2011	254.5736	-87.2608	-2.4994	unid dolphin	2	INOCAR
2011	255.4028	-89.0038	-1.9269	common dolphin	60	INOCAR
2011	256.3201	-90.0057	-0.165	sei-Brydes whale	2	INOCAR
2011	256.3847	-90.2153	-0.0944	sei-Brydes whale	1	INOCAR
2011	256.4431	-90.4118	-0.0286	sperm whale	1	INOCAR
2011	256.6299	-91.0667	0.1899	common dolphin	50	INOCAR
2011	256.6576	-91.1593	0.2206	unid large whale	3	INOCAR
2011	256.6625	-91.1751	0.2245	unid small whale	1	INOCAR
2011	256.7368	-91.4486	0.3143	blue whale	1	INOCAR
2011	257.2889	-91.9997	-0.1709	unid large whale	1	INOCAR
2011	257.3021	-92.0017	-0.2107	blue whale	2	INOCAR
2011	257.3062	-92.0012	-0.2255	blue whale	2	INOCAR
2011	257.3236	-91.9998	-0.2801	unid large whale	1	INOCAR
2011	257.3236	-91.9998	-0.2801	blue whale	2	INOCAR
2011	257.3285	-91.9998	-0.2962	unid baleen whales	1	INOCAR
2011	257.3361	-91.9992	-0.322	blue whale	2	INOCAR
2011	257.3451	-91.9999	-0.3497	blue whale	1	INOCAR
2011	257.3451	-91.9999	-0.3497	unid large whale	2	INOCAR
2011	257.3521	-92.0019	-0.37	unid baleen whales	5	INOCAR
2011	257.3632	-92.0005	-0.4167	blue whale	1	INOCAR
2011	257.5035	-91.9994	-0.5705	unid large whale	1	INOCAR
2011	257.6611	-92.0048	-1.0028	sperm whale	5	INOCAR
2011	257.6931	-92.001	-1.0402	sperm whale	2	INOCAR
2011	257.7125	-92.0012	-1.1005	common dolphin	30	INOCAR
2011	257.734	-92.0012	-1.1669	unid dolphin	20	INOCAR
2011	258.659	-91.5922	-2.0242	unid dolphin	70	INOCAR
2011	258.659	-91.5922	-2.0242	unid small whale	1	INOCAR
2011	259.3014	-90.433	-0.9792	humpback whale	2	INOCAR
2011	259.3139	-90.4027	-0.961	humpback whale	1	INOCAR
2011	259.3632	-90.2956	-0.8939	unid large whale	1	INOCAR
2011	261.7125	-90.2601	-0.9023	bottlenose dolphin	5	INOCAR

Year	Day of Year	Longitude	Latitude	Cetacean	Group Size	Program
2011	262.4299	-88.3393	-1.2535	unid baleen whales	1	INOCAR
2011	262.4722	-88.2133	-1.2779	unid large whale	1	INOCAR
2011	262.7174	-87.48	-1.4156	unid dolphin	50	INOCAR
2011	262.7188	-87.48	-1.4156	sperm whale	1	INOCAR
2011	262.7292	-87.4475	-1.4218	unid large whale	1	INOCAR
2011	263.6583	-84.4635	-1.9835	common dolphin	80	INOCAR
2011	263.7375	-84.1974	-2.0341	pilot whale	6	INOCAR
2011	264.4611	-81.9428	-2.4574	Risso's Dolphin	6	INOCAR
2011	264.5458	-81.7132	-2.4999	pilot whale	30	INOCAR
2011	264.5715	-81.6338	-2.5146	Risso's Dolphin	60	INOCAR
2011	264.5903	-81.5717	-2.5278	striped Dolphin	60	INOCAR
2011	264.6354	-81.4225	-2.556	unid large whale	1	INOCAR
2003	285.36	-92.2833	-1.4667	unid large whale	3	NOAA
2003	284.43	-89.1	0.1833	unid small whale	10	NOAA
2003	313.36	-80.0667	0.8667	unid dolphin	3	NOAA
2003	284.35	-90.5833	0.3833	unid dolphin	1	NOAA
2003	284.4	-90.7	0.3	unid dolphin	10	NOAA
2003	284.68	-90.7167	-0.4167	unid dolphin	20	NOAA
2003	311.42	-80.9667	-1.75	humpback whale	2	NOAA
2003	311.57	-81.0333	-1.2667	humpback whale	1	NOAA
2003	311.73	-81.05	-1.1	humpback whale	2	NOAA
2003	312.49	-80.3	0.15	humpback whale	2	NOAA
2003	312.58	-80.2167	0.4	humpback whale	3	NOAA
2003	312.33	-80.6	0.0167	Brydes whale	6	NOAA
2003	285.32	-92.1167	-1.4333	pilot whale	5	NOAA
2003	311.55	-81.0167	-1.3167	bottlenose dolphin	6	NOAA
2003	313.28	-80.2167	0.9167	bottlenose dolphin	2	NOAA
2003	313.49	-80.0167	1.2333	bottlenose dolphin	67	NOAA
2003	284.47	-90.9167	0.0833	common dolphin	168	NOAA
2003	285.28	-91.9833	-1.4167	common dolphin	181	NOAA
2003	285.38	-92.2333	-1.5167	common dolphin	390	NOAA
2003	285.41	-92.3833	-1.5333	common dolphin	90	NOAA
2003	285.52	-92.6333	-1.6667	common dolphin	128	NOAA
2003	285.6	-92.9	-1.5833	common dolphin	281	NOAA
2003	312.28	-80.7333	0	common dolphin	25	NOAA
2003	283.74	-89.35	1.45	striped Dolphin	62	NOAA
2003	284.31	-90.6167	0.55	striped Dolphin	39	NOAA
2003	284.33	-90.6333	0.4833	striped Dolphin	183	NOAA
2003	284.36	-90.6833	0.4167	striped Dolphin	33	NOAA
2003	284.48	-90.95	0.0667	striped Dolphin	178	NOAA
2003	285.73	-93.3167	-1.7	striped Dolphin	94	NOAA
2003	285.77	-93.4833	-1.7167	striped Dolphin	11	NOAA
2003	312.36	-80.5167	0.05	Pantropical spotted dolphin	120	NOAA
2003	312.69	-80.2167	0.7	Pantropical spotted dolphin	90	NOAA
2003	313.31	-80.1	0.9667	Pantropical spotted dolphin	24	NOAA
2003	313.38	-80.0167	0.9667	Pantropical spotted dolphin	61	NOAA
2003	313.57	-79.7	1.0833	Pantropical spotted dolphin	255	NOAA
2003	283.77	-89.4333	1.45	Pantropical spotted dolphin	169	NOAA
2000	312.67	-80.7667	-0.3	Stenella sp.	360	NOAA
2000	310.26	-81.1667	-2.5167	common dolphin	80	NOAA
2000	280.47	-83.4833	-0.6167	striped Dolphin	80	NOAA
2000	280.69	-83.15	-0.3	striped Dolphin	13	NOAA
2000	281.28	-81.5833	-0.9667	striped Dolphin	24	NOAA
2000	282.36	-81.8667	0.9667	striped Dolphin	19	NOAA
2000	282.29	-81.65	0.8	striped Dolphin	32	NOAA
2000	310.58	-82.1333	-2.0833	common dolphin	248	NOAA
2000	310.48	-81.8333	-2.2333	common dolphin	146	NOAA
2000	310.53	-81.9667	-2.1167	common dolphin	365	NOAA
2000	311.29	-83.7	-1.2	common dolphin	173	NOAA
2000	311.35	-83.6167	-1.0667	common dolphin	131	NOAA
2000	312.38	-81.2833	-0.9667	common dolphin	1025	NOAA
2000	284.34	-94.95	0.8333	bottlenose dolphin	15	NOAA
2000	312.3	-81.5667	-0.9333	bottlenose dolphin	73	NOAA
2000	312.33	-81.5167	-0.9667	bottlenose dolphin	4	NOAA
2000	312.44	-81.1667	-0.95	bottlenose dolphin	15	NOAA
2000	312.47	-81.05	-0.95	bottlenose dolphin	3	NOAA
2000	312.47	-81.05	0.95	bottlenose dolphin	39	NOAA
2000	314.57	-79.7833	1.4167	Rissos Dolphin	4	NOAA
2000	312.3	-81.5667	-0.9333	pilot whale	120	NOAA
2000	312.44	-81.1667	-0.95	pilot whale	13	NOAA
2000	284.34	-94.95	0.8333	pilot whale	17	NOAA
2000	312.35	-81.4667	-0.9333	unid ziphiid	4	NOAA
2000	310.28	-81.15	-2.55	unid mesoplondant	1	NOAA
2000	311.59	-83.5	-0.2667	unid mesoplondant	1	NOAA
2000	312.39	-81.3333	-1.0167	unid mesoplondant	1	NOAA
2000	310.33	-81.35	-2.4667	blue whale	1	NOAA
2000	284.31	-94.8833	0.9333	unid dolphin	11	NOAA
2000	311.57	-83.5	-0.3167	unid dolphin	1	NOAA
2000	312.27	-81.7167	-1.0167	unid dolphin	50	NOAA
2000	312.46	-81.1333	-0.9167	unid dolphin	6	NOAA
2000	313.4	-82.05	1.0333	unid dolphin	1	NOAA
2000	314.58	-79.7333	1.4	unid dolphin	2	NOAA
2000	310.26	-81.1667	-2.5	unid large whale	1	NOAA
2000	311.39	-81.1667	-0.8833	unid large whale	1	NOAA
2000	283.75	-81.1667	1.4833	sei-Brydes whale	3	NOAA
1999	313	-84.8833	-2	striped Dolphin	28	NOAA
1999	313	-84.8833	-2	striped Dolphin	87	NOAA
1999	313	-85.05	-1.9	striped Dolphin	102	NOAA

Year	Day of Year	Longitude	Latitude	Cetacean	Group Size	Program
1999	313	-85.6	-1.3667	striped Dolphin	35	NOAA
1999	314	-87.55	0.4	striped Dolphin	19	NOAA
1999	314	-87.8	0.5333	striped Dolphin	81	NOAA
1999	314	-87.6	0.7	striped Dolphin	11	NOAA
1999	314	-87.55	0.8333	striped Dolphin	21	NOAA
1999	314	-87.1333	1.2333	striped Dolphin	13	NOAA
1999	285	-89.4667	0.3167	striped Dolphin	30	NOAA
1999	285	-90.4833	-0.0833	striped Dolphin	53	NOAA
1999	313	-84.8	-2	striped Dolphin	28	NOAA
1999	285	-90.0833	0.0667	common dolphin	45	NOAA
1999	285	-90.7	0	common dolphin	764	NOAA
1999	285	-90.9167	-0.2	common dolphin	42	NOAA
1999	312	-83.1333	-3.4667	common dolphin	158	NOAA
1999	312	-83.3	-3.2167	common dolphin	433	NOAA
1999	312	-83.3167	-3.2	common dolphin	110	NOAA
1999	312	-83.5	-3.1	common dolphin	332	NOAA
1999	312	-83.5333	-3.1	common dolphin	30	NOAA
1999	312	-83.5833	-3.1	common dolphin	17	NOAA
1999	313	-84.9	-2	common dolphin	32	NOAA
1999	313	-85.0833	-1.85	common dolphin	32	NOAA
1999	313	-85.1667	-1.7833	common dolphin	9	NOAA
1999	313	-85.6	-1.3667	common dolphin	76	NOAA
1999	313	-85.6667	-1.2	common dolphin	125	NOAA
1999	312	-83.2333	-3.1833	pilot whale	30	NOAA
1999	312	-83.65	-3.0333	pilot whale	34	NOAA
1999	285	-90.6667	-0.1667	sperm whale	4	NOAA
1999	285	-90.1	0.0167	unid ziphiid	1	NOAA
1999	313	-84.9833	-1.9333	unid ziphiid	1	NOAA
1999	313	-85.7167	-1.2667	unid ziphiid	1	NOAA
1999	313	-85.6833	-1.3	unid ziphiid	1	NOAA
1999	313	-84.9167	-1.9667	unid mesoplondant	4	NOAA
1999	313	-85.3833	-1.6833	unid mesoplondant	3	NOAA
1999	313	-85.5833	-1.4333	unid mesoplondant	2	NOAA
1999	313	-85.6833	-1.3	unid mesoplondant	2	NOAA
1999	313	-85.55	-1.5	Cuviers beaked whale	2	NOAA
1999	314	-87.4167	0.95	Cuviers beaked whale	3	NOAA
1999	312	-83.15	-3.4167	blue whale	1	NOAA
1999	285	-90.8	-0.0667	Brydes whale	1	NOAA
1999	285	-90.9667	-0.15	Brydes whale	1	NOAA
1999	312	-83.1667	-3.3167	Brydes whale	1	NOAA
1999	314	-87.6833	0.65	Brydes whale	2	NOAA
1999	285	-89.5333	0.1833	unid dolphin	2	NOAA
1999	285	-89.8333	0	unid dolphin	15	NOAA
1999	285	-89.9	0.2	unid dolphin	82	NOAA
1999	285	-90.5667	0	unid dolphin	37	NOAA
1999	291	-91.9	-2.9833	unid dolphin	5	NOAA
1999	312	-83.4333	-3.0333	unid dolphin	10	NOAA
1999	313	-84.7833	-1.9833	unid dolphin	33	NOAA
1999	313	-84.8667	-1.95	unid dolphin	40	NOAA
1999	313	-85.2	-1.8833	unid dolphin	3	NOAA
1999	313	-85.2333	-1.7667	unid dolphin	5	NOAA
1999	313	-85.8	-1.35	unid dolphin	50	NOAA
1999	314	-87.6833	0.6667	unid dolphin	1	NOAA
1999	314	-87.1333	1.3	unid dolphin	98	NOAA
1999	291	-91.5833	-2.3667	unid small whale	1	NOAA